The Saguaros of "Section 17" in Saguaro National Park:

Re-survey of a One-Square-Mile Section First Surveyed in 1941

Final Report to Friends of Saguaro National Park
May 21, 2013

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Most importantly, we are grateful to Tom Orum, Nancy Ferguson, and Ray Turner, who have dedicated so many years of their lives, many as volunteers, to long-term monitoring of the saguaro in Saguaro National Park. Tom and Nancy generously shared their data for this project, volunteered during the BioBlitz, and provided their support and encouragement throughout the year. Saguaros live longer than we humans do – but fortunately Tom, Nancy and Ray have helped sow the seeds for the next generation of students.

Executive Summary

We re-surveyed all saguaro cacti (*Carnegiea gigantea*) in a 1-square mile section (section 17, R16E, T14S) in the Rincon Mountain District, Saguaro National Park, that was first surveyed in 1941. This survey was a "citizen science" project initiated during the 2011 BioBlitz at the park. Student interns trained and supervised more than 300 middle and high school students and adult volunteers during October 2011 through July 2012. We systematically searched 64 4-hectare subplots, measured each saguaro detected, and recorded its coordinates, nurse tree, and the number of bird holes and arms. In 1941-1942, researchers at the park measured 13,304 saguaros, with 80% being > 3.66 m (12 ft) tall. In 2011-2012, we measured 9,034 saguaros, with 80% being < 3.66 m tall. In general, the saguaro population in 1941 was dominated by large individuals estimated to be more than 50 years of age, whereas today the population is dominated by younger individuals that have germinated since 1960. Our results complement and are consistent with a long-term study of six smaller plots surveyed annually within Section 17 for every year since 1941. They indicate that the saguaro population in the Cactus Forest, which was in decline for many decades before and after the establishment of Saguaro National Monument in 1933, has re-bounded due to a surge in establishment of young saguaros during the period from the 1960s through the early 1990s. However, establishment of new saguaros has all but ceased since the mid-1990s, presumably in response to drought conditions.

Introduction

Saguaro National Park has a rich history of ecological research and intensive study of the giant saguaro (*Carnegiea gigantea)* cactus (McAuliffe 1993, 1996; Ahnmark and Swann 2009). The Rincon Mountain District of the park was originally established as a national monument in 1933 by President Herbert Hoover (the Tucson Mountain District was added in 1962, and Saguaro was designed as a national park in 1994). The area's "outstanding scientific interest because of the exceptional growth…of various species of cacti, including the so-called giant cactus" formed the basis for federal protection of this landscape.

Shortly after the monument opened to the public, in the late 1930s, park staff observed a major die-off of saguaros in the so-called "Cactus Forest" area in the foothills of the Rincons (Fig. 1). Subsequently, researchers from the US Department of Agriculture Bureau of Plant Industry were asked to study the problem. Lake S. Gill and Paul C. Lightle observed mortality in large numbers, with many older cacti emitting a black fluid that they hypothesized was associated with a contagious bacterial infection (Gill and Lightle 1942). In order to test treatments for the bacterial infection in 1941, Gill and Lightle organized a large-scale study on a 640 acre area of the cactus forest within the monument – Section 17 of Range 16 East, Township 14 South, typically referred to as "Section 17" – where they conducted a census of all saguaro cacti within the plot, and collected height and size-class data. Section 17 was divided into 64 10-acre square subplots. On the 32 plots in the southern half of the section, all saguaros that appeared to be suffering from bacterial infection were removed mechanically (Figs. 2-3), whereas all cacti in the northern half of the section were left untreated. Initial demographic results indicated an aging population with little recruitment, which concerned researchers and made them question the viability of the species given the possibility of a contagious bacterial disease. However, by 1946 the researchers had found no significant difference between the treatment and control areas (Gill and Lightle 1946) and in 1950 they concluded that the disease did not appear to be contagious (Gill 1951). Most researchers (e.g., Steenberg and Lowe 1983) now believe that the die-off was caused by extreme freeze events in 1937 and 1939 that had an extreme effect on a local saguaro population that was dominated by older, weaker individuals.

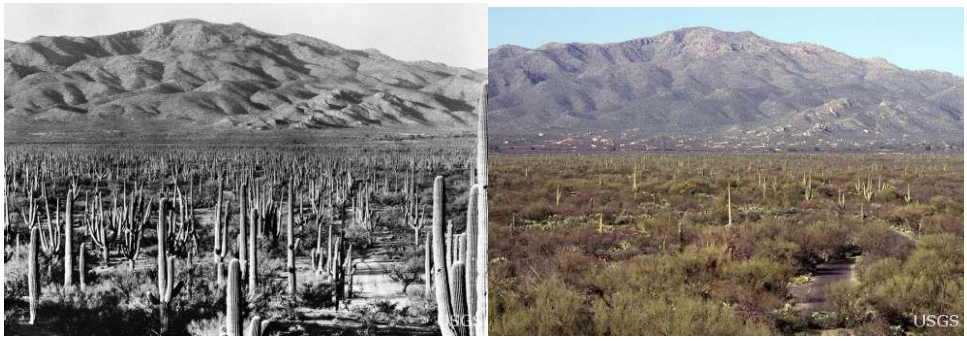


Figure 1 – The cactus forest in 1935 (left), and in 2010 (right). 1935 photographer unknown. 2010 photo by Ray Turner.

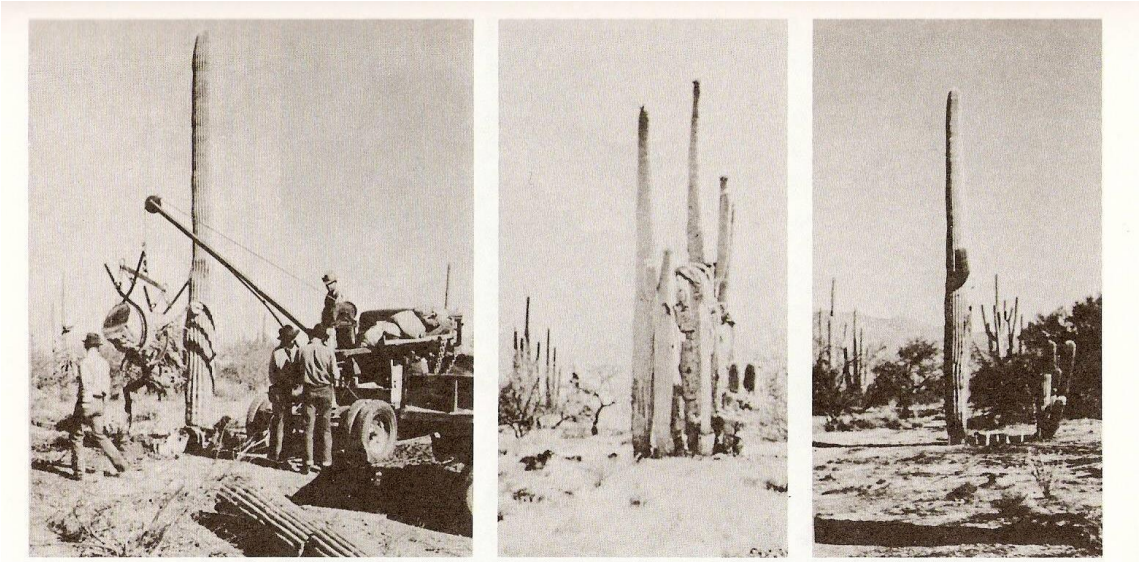


Figure 2 (above). Photos from the original report (Gill and Lightle 1942, reprinted in Steenbergh and Lowe 1983), showing methods for removing diseased cacti from the southern half of Section 17. (below) Diseased saguaros were cut into pieces, hauled to pits, doused with kerosene and pesticide, and buried. Photo source unknown.

Although the large-scale experiment in Section 17 was effectively concluded in 1946, research and monitoring in the area has continued to this day. In particular, Gill, Lightle, and Craig Bryan continued to monitor saguaros on six 10-acre subplots within the section. These plots have been surveyed ever since on an annual basis – after Bryan by Stan Alcorn and his colleagues, and more recently by Tom Orum and Nancy Ferguson – making Section 17 the site of one of the longest running monitoring studies conducted in any national park. In addition, many other studies have been conducted in Section 17. Appendix A and Ahnmark and Swann (2009) provide a history of the removal experiment and other research in Section 17.

Long-lived species, like the giant saguaro, require long-term site-specific monitoring studies in order to determine whether changes in population dynamics represent significant trends or short-term random variations (Pierson and Turner 1998). The results of research in Section 17 and elsewhere in Saguaro National Park indicate that the population of this plant can be highly dynamic on a decadal scale. Saguaro recruitment in the Cactus Forest was very low from the 1910s through the 1940s (Shreve 1911, Gill and Lightle 1942); subsequent studies (Alcorn and May 1962) identified the negative effects of cattle grazing on saguaro establishment through trampling and crushing, among other causes. In addition, the prolific harvesting of wood for lime kilns and other human activities removed vital nurse plants that sheltered young saguaros (McAuliffe 1996). Large-scale removal of wood ended when the monument was established, and grazing ceased in the Cactus Forest area in 1958, which undoubtedly affected recruitment and recovery of the population (McAuliffe 1996).

Following Gill and Lightle's large-scale study, saguaros continued to decline in Section 17 for many years. By 1962, researchers predicted that, "assuming no changes in the rate of decline in the future, this plant population will theoretically (at the rate of 95% level of confidence) cease to exist between 1995 and 1998" (Alcorn and May 1963). Surveys conducted in the 1970s concluded that the saguaro population as a whole was still declining, but by the 1980s researchers (e.g., Steenbergh and Lowe 1983) noticed that young saguaros were becoming established. By the end of the decade, long-term monitoring results were beginning to indicate that juveniles had proliferated over the previous two decades and that an overall increase in visible saguaro would soon occur (Turner 1989, Orum et al. 2010). In 1990, Saguaro National Park established 45 permanent plots, randomly located throughout the park, to study epidermal browning of saguaro cacti and to provide baseline demographic data for long-term monitoring (Duriscoe and Graban 1991). Results of the second and third Saguaro Census (Turner and Funicelli 2001, O'Brien et al. 2011) have confirmed earlier predictions that the saguaro population is recovering throughout the park. In addition, data from the six long-term study plots established by Gill and Lightle indicate that the saguaro population has also increased dramatically in Section 17 (Orum et al. 2010).

The objective of this study was to resample Section 17 in its entirety for the first time in 70 years. Age structure data are important to ecologists and resource managers because they

provide an estimate of overall population health (Pierson and Turner 1998) as well as monitor the pattern of vegetation change over time (Bakker et al. 1996). A thorough demographic study on a large scale is valuable for land management and provides insight into the future state of an iconic and ecologically important southwestern cactus species. Although the six long-term plots in the section have been monitored continuously for many decades, the entire 640-square acre area had not been resurveyed since the original 1941 census. Fortunately, the original map and detailed log books created by Lake Gill and Paul Lightle had been preserved by Tom Orum and Nancy Ferguson, who generously provided copies to the park; all of these data were digitized in a heroic effort by graduate student Theresa Foley.

In addition, the 70th anniversary of the original survey of Section 17 coincided with the 2011 BioBlitz, a huge citizen science event scheduled in Saguaro National Park in October, 2011. Staff at the park felt that the BioBlitz presented a great opportunity to kick off a major project that would highlight the research history of Saguaro National Park, to involve literally hundreds of high school students and volunteers, and to educate Tucsonans about the park's namesake plant that is such an iconic symbol of the American Southwest.

Study Area

Saguaro National Park is located near Tucson, Arizona. The Park is divided into two districts: the Tucson Mountain District (TMD), which borders the Tucson Mountain Park on the west side of Tucson, while the Rincon Mountain District (RMD) is on the east side (Fig. 3). Section 17 is located on the northwestern edge of RMD, on the southeast corner of the Freeman Road and Broadway Road Intersection (Fig. 4a). The area is relatively flat with non-rocky soil, intermittent washes, and Sonoran desert scrub vegetation.

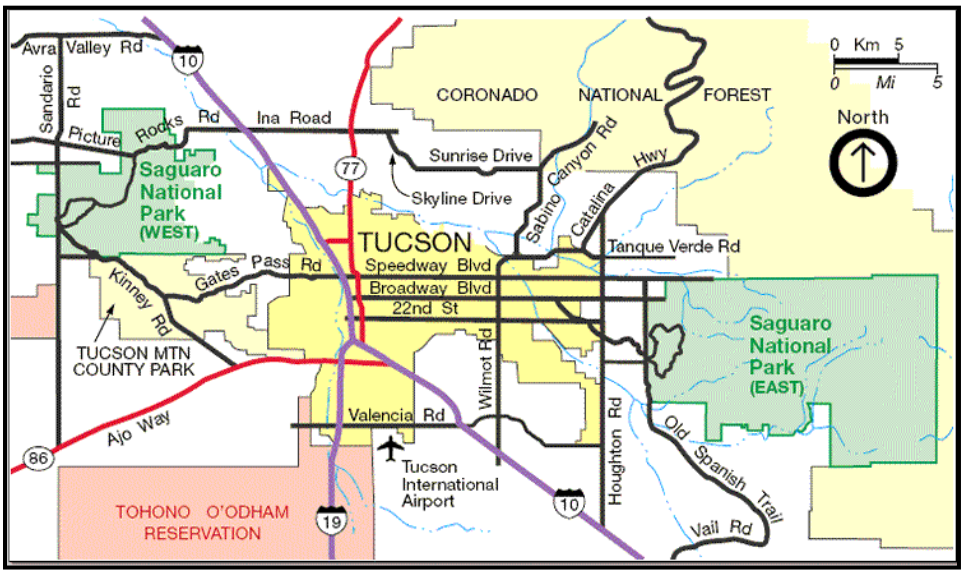
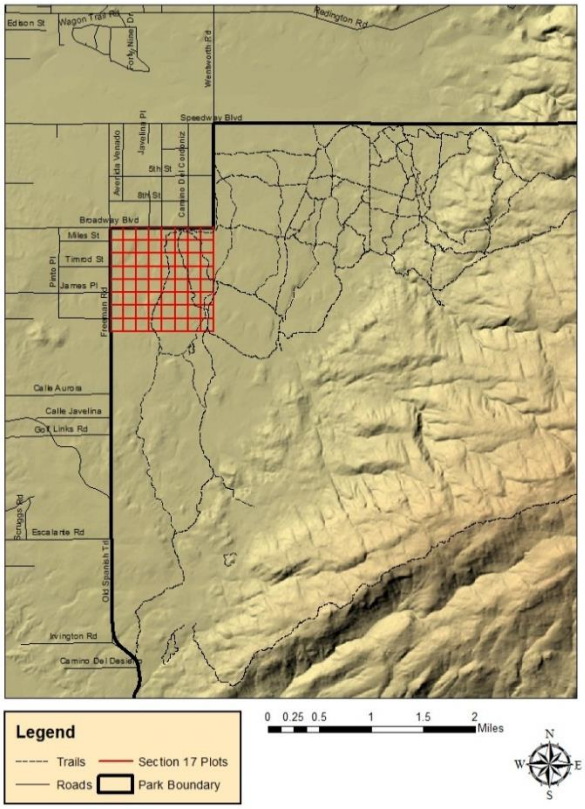


Figure 3. Location map of Saguaro National Park, Arizona, showing Rincon Mountain District east of Tucson and Tucson Mountain District west of Tucson.



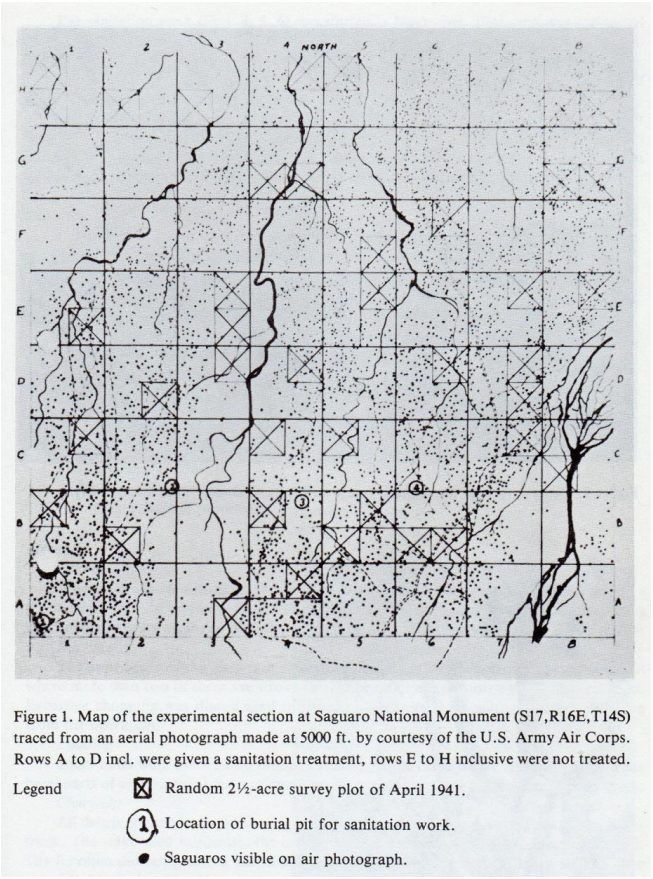


Figure 4a (left). Location of Section 17 in NE corner of Rincon Mountain District. Figure 4b (right). Original map of all large saguaros mapped in Section 17 in 1941.

Methods

We did not attempt to replicate the methods of Gill and Lightle (1942), who collected detailed data on health characteristics of all of the saguaros in Section 17, but instead of measuring every saguaro, placed them into size categories at six-foot intervals. Also, Gill and Lightle (1942) did not map smaller saguaros nor identify the individual saguaros on their map (Fig. 4b). Instead, we followed the field sampling protocols established by O'Brien et al. (2011) when applicable with the addition of recording the coordinates and nurse tree for all saguaros. See Appendix B for detailed sampling protocols. The 64 plots in Section 17 were sampled between October 2011 and July 2012 (hereafter, for simplicity, we refer to all results as "2012"). Individual plots measured 200 meters by 200 meters. We located the corners of each plot with a GPS unit and marked the four sides of each plot with flagging at approximately 20-meter intervals. Crews separated into groups of 3-5 individuals with one leader and systematically searched for saguaro cacti throughout the plot. Each saguaro was marked with a numbered pin flag when found, measured with a folding rule to the nearest 0.01 m, and the location was recorded with a GPS unit. Saguaros taller than four meters were measured with a clinometer and

tape measure, using two independent observers, to the nearest 0.1 m (Appendix B). In addition, we counted the number of bird holes (round holes that showed evidence of an inner chamber) and arms.

This surveying process required three "passes" through the plot: one pass to record, one pass to check for any missed saguaros, and a third pass to collect survey flags. The crew leader maintained responsibility for flagging the plot perimeter, double-checking the accuracy of measurements, monitoring crew progress and safety, and facilitating efficient communication among crew members. The group leaders were responsible for data quality, on-the-ground training, and educating participants about the project, saguaros, and the park.

We used volunteer "citizen scientists" for most of the data collection, except for a subset of plots that were completed during the summer of 2012 by the park's Youth Internship Program crew. Many of the volunteers were high school and middle school students, especially from the Arizona College Preparatory Academy, who participated during the BioBlitz on October 21, 2011 as well as throughout the following school year. We also recruited volunteers through the park's web site and by contacting groups such as hiking clubs, scout troops, college groups, and others. Volunteers were provided with pre-visit information (Appendix C) and then received an on-site training before going into the field. The crew leader was a trained park biological technician or very experienced intern (for most of the project, Student Conservation Intern Irene Weber was in this role). Small group leaders were either park staff or experienced volunteers who had participated in the activity previously and had the knowledge and experience to train volunteers on data collection, clinometer and GPS use, and other skills.

Data Analysis

All collected field data were entered into an Excel spreadsheet by a technician and checked by a second technician. Data from each plot were kept in individual spreadsheets before being aggregated into a single spreadsheet. In addition to entering the data collected during the 2012 census, Theresa Foley also digitized the written record from 1941 into a series of Excel spreadsheets. We examined differences between the 1941 census and 2012 census by directly comparing the number of saguaros observed on each plot and summing by height class. Height class definitions and the corresponding age range according to Steenbergh and Lowe (1983) are given in Table 1.

Measuring each saguaro allowed us to use height-age equations from Steenbergh and Lowe (1977) to determine germination dates and provide a clearer picture of the recruitment and regeneration of the saguaro cactus in Section 17. The regression equation is:

$$\log Y = -0.309 + 0.884 \log X + 0.609 (\log X)^2$$

where Y equals stem height in centimeters and X equals age in years (Steenbergh and Lowe 1977, pg. 140).

In order to solve for age, the equation was rearranged and modified to:

$$X=10^{(-0.609+.884*SQRT(1.493+2*\log(Y)))}$$

where *Y* equals stem height in centimeters and *X* equals age in years. We modified and corrected the original equation so that the results conformed to the age-height tables presented in Steenbergh and Lowe (1977). The uncorrected equation did not determine age from height correctly according to the age-height tables. This equation is applicable only for saguaro cacti less than 2.2 meters, or approximately 33 years. After this age, saguaros change growth form and rate. Since our study focused on recent germination and establishment, the given equation should be sufficient.

After determining the germination date for saguaro cacti less than 2.2 meters tall, we applied a correction factor to account for juvenile saguaro cacti that may have been overlooked during surveys. The correction factor is based on data from six study plots in RMD that are sampled annually and estimates mean detection probability based on the age-height relationship of known saguaros (Orum et al. 2011).

Results

Changes in the saguaro population, 1941-2011. We counted 9,023 saguaro cacti in the 2012 census (Fig. 6). Total numbers of saguaro cacti are 31.4% lower than the 1941 count of 13,304. Gill and Lightle's 1941 census study reported a count of 12,968 saguaro cacti within Section 17, but we discovered slight mathematical errors when digitizing the raw data from the 1941 logbooks. The mistake is understandable given the technology of the time. Each plot averaged 144.1 saguaros in 2012, 61.4 fewer than the 205.4 average in 1941. The range of observed saguaros on each plot varied greatly for both periods. In 1941, the census found that plots had a minimum value of 21 and a maximum of 519. The 2012 data has a similar range, with a low of 20 and a max of 546. See Appendix D for plot-level histograms comparing observed saguaros between 1941 and 2012.

Height Class	Feet	Meters	Age
1	0-6ft	0-1.8m	0-36
2	6-12ft	1.8-3.66m	37-52
3	12-18ft	3.66-5.49m	53-68
4	18-24ft	5.49-7.32m	68-85
5	25+	7.33+	85+

Table 1 – Height class definitions (Gill and Lightle 1942) and corresponding age based on model of Steenbergh and Lowe (1983).

We assessed change at the plot level in addition to the global scale (Fig. 5). Saguaro cacti density declined from 1941 to 2012 for most plots, which reflects the global trend. Density declined by 50% or more in nearly 22% of all plots. The most negative change occurred along the drainage that runs through the third and fourth columns of the Section 17 plot array. Nearly 19% of plots increased density from 1941 to 2012, including 75% of the plots along Broadway Road. We plotted the number of saguaros found on each plot in Figure 6 to test for correlation. The r-squared value of .607 is a strong indication that high density plots in 1941 retained high density in 2012. This is also true for low density plots.

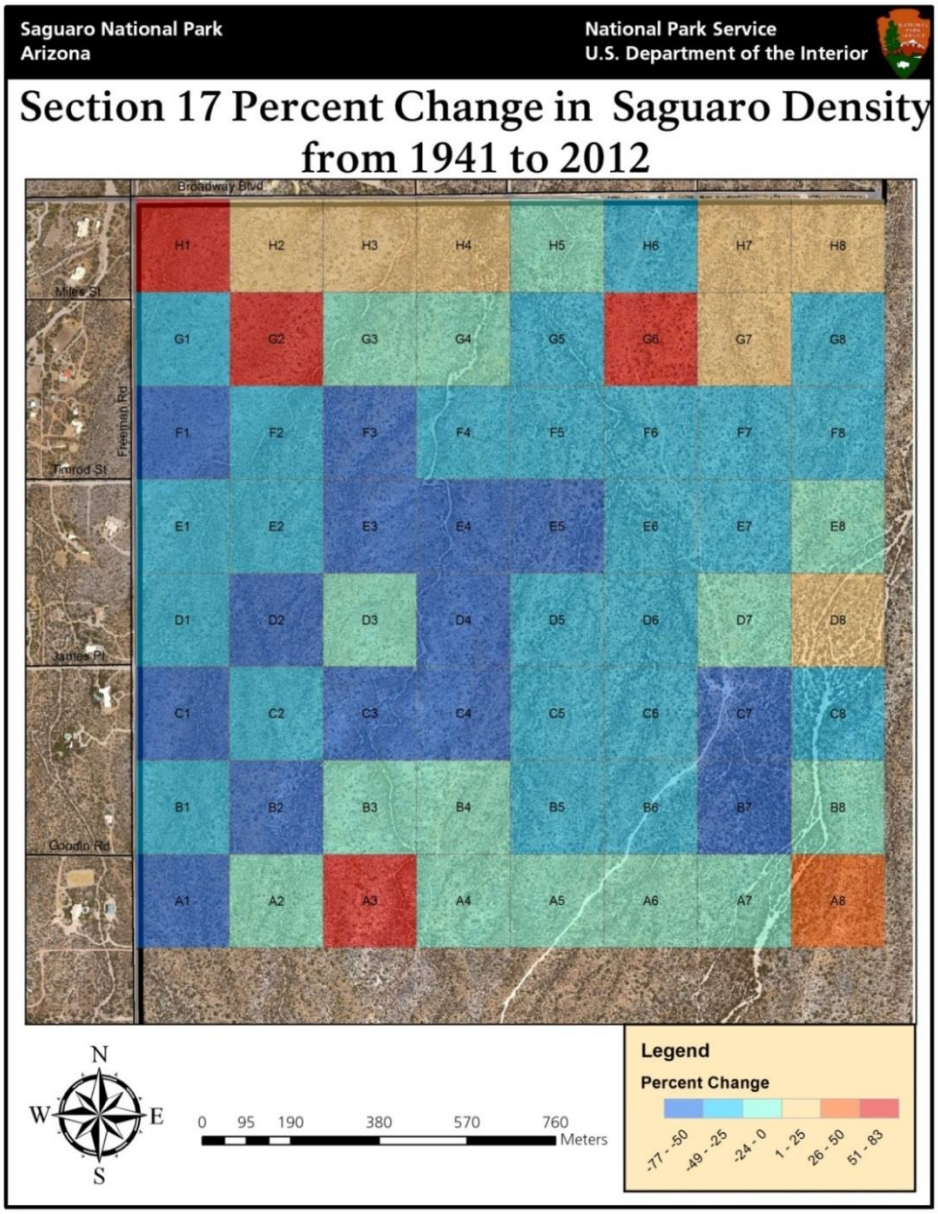


Figure 5 – Changes in the density of saguaro cacti for each plot in Section 17. Overall trends show a decline in density from 1941 to 2012, which is consistent with other results. 12 plots of 64 showed an increase in density.

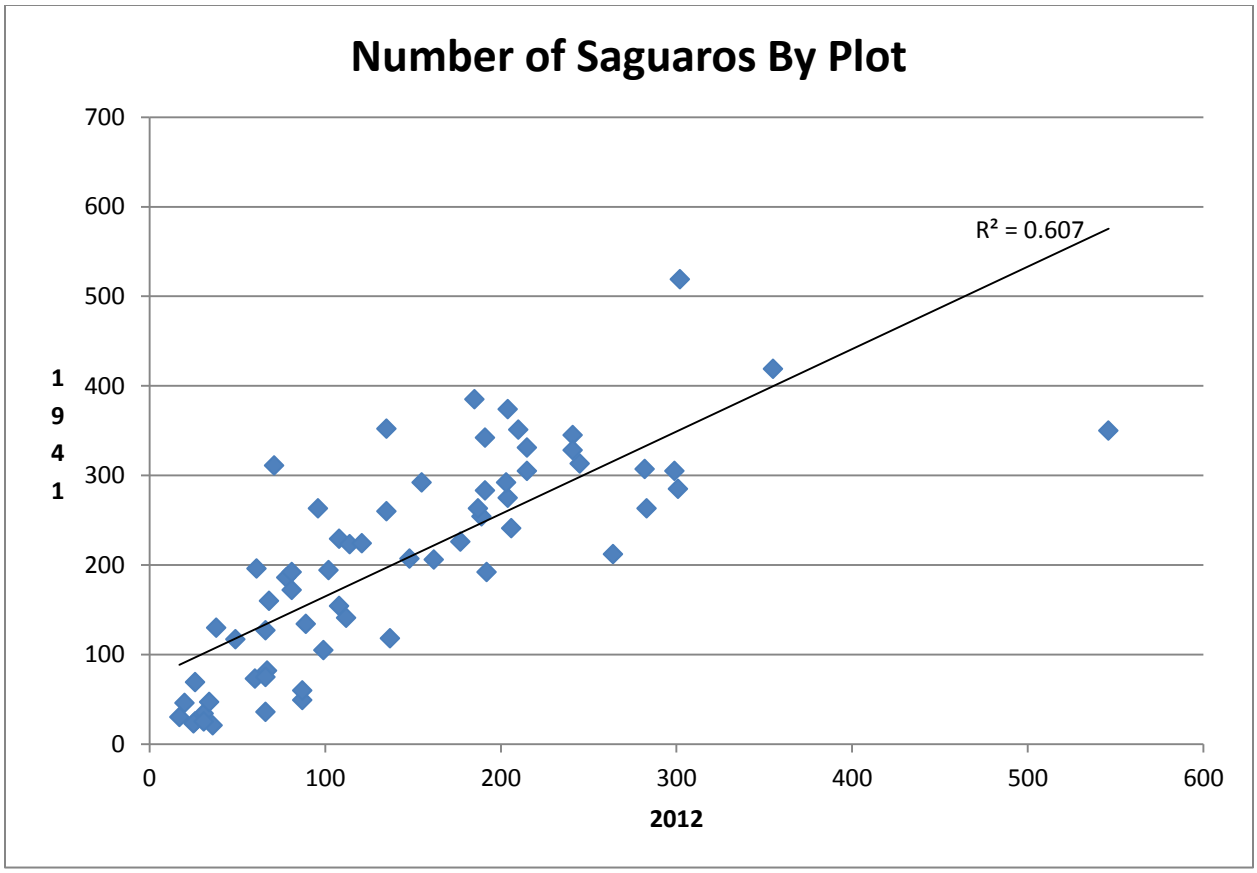


Figure 6 – Correlation of the number of saguaro cacti per plot from the 1941 and 2012 studies. The r-squared value indicates a moderately high level of correlation, which means plots with few saguaro cacti in 1941 had relatively few cacti in 2012.

The demographic composition of the population has also changed since 1941. Figure 7 confirms the observations of Gill and Lightle (1942) and Steenbergh and Lowe (1983) that the saguaro population was dominated by older, taller individuals in the past with little recruitment in earlier decades. In 2012, the height class data indicates that age composition demographics are no longer dominated by plants greater than 60 years old. The smallest height class, cacti that are less than 1.8 meters, represented 57.1% of the total saguaro population in 2012. This finding indicates that the majority of the current saguaro population is less than 36 years old. Saguaros in this height class established in 1976 or later and it is likely that many saguaros would not have been detectable by Steenbergh and Lowe (1983). The establishment trends over the past 30 years show a drop in recruitment since the 1990's (Fig. 8a). 1984 was the peak saguaro recruitment year, and 384 saguaro cacti germinated.

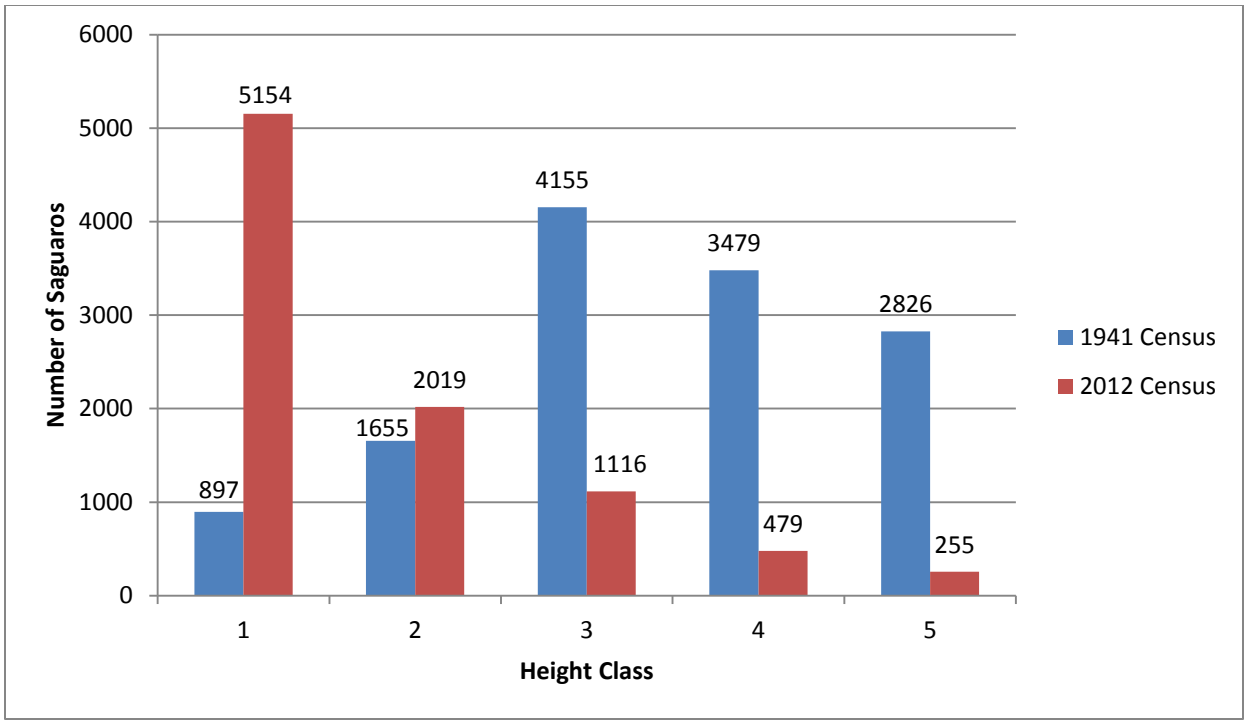


Figure 7 – Number of saguaros by height class in 2012 and 1941. See Table 1 for height class values.

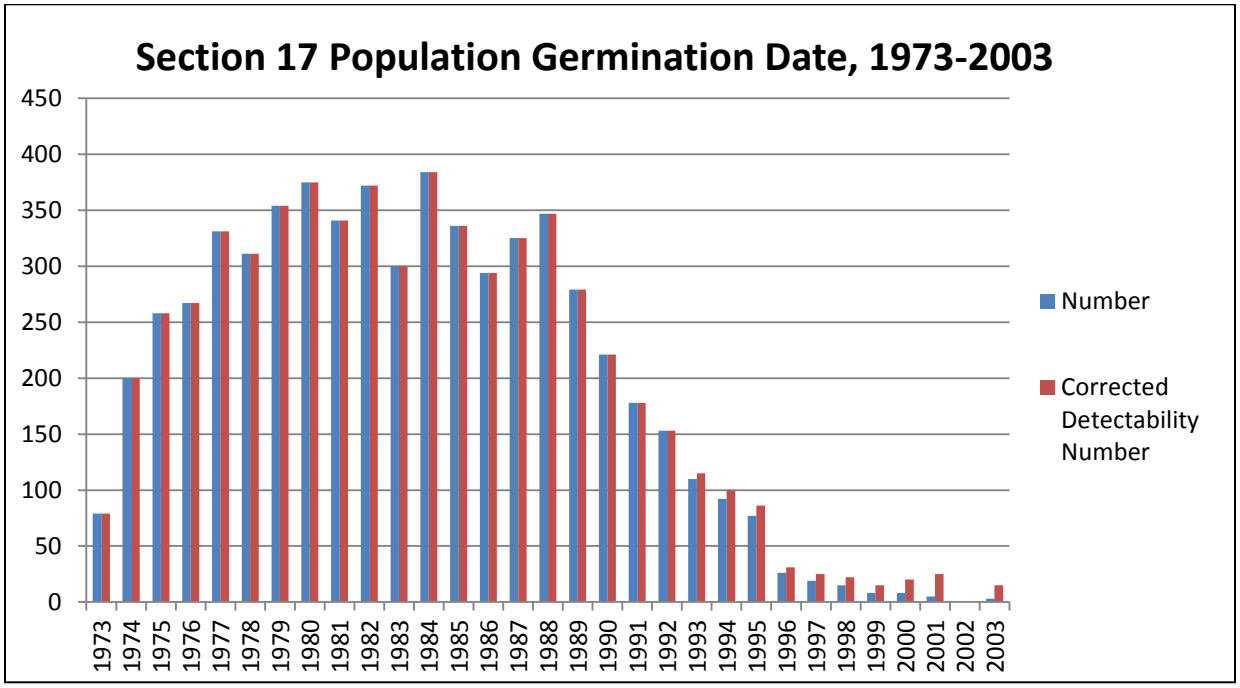


Figure 8a – Number of saguaro cacti that germinated annually, 1973 to 2003. Corrected detectability number derived from Orum et al. (2011).

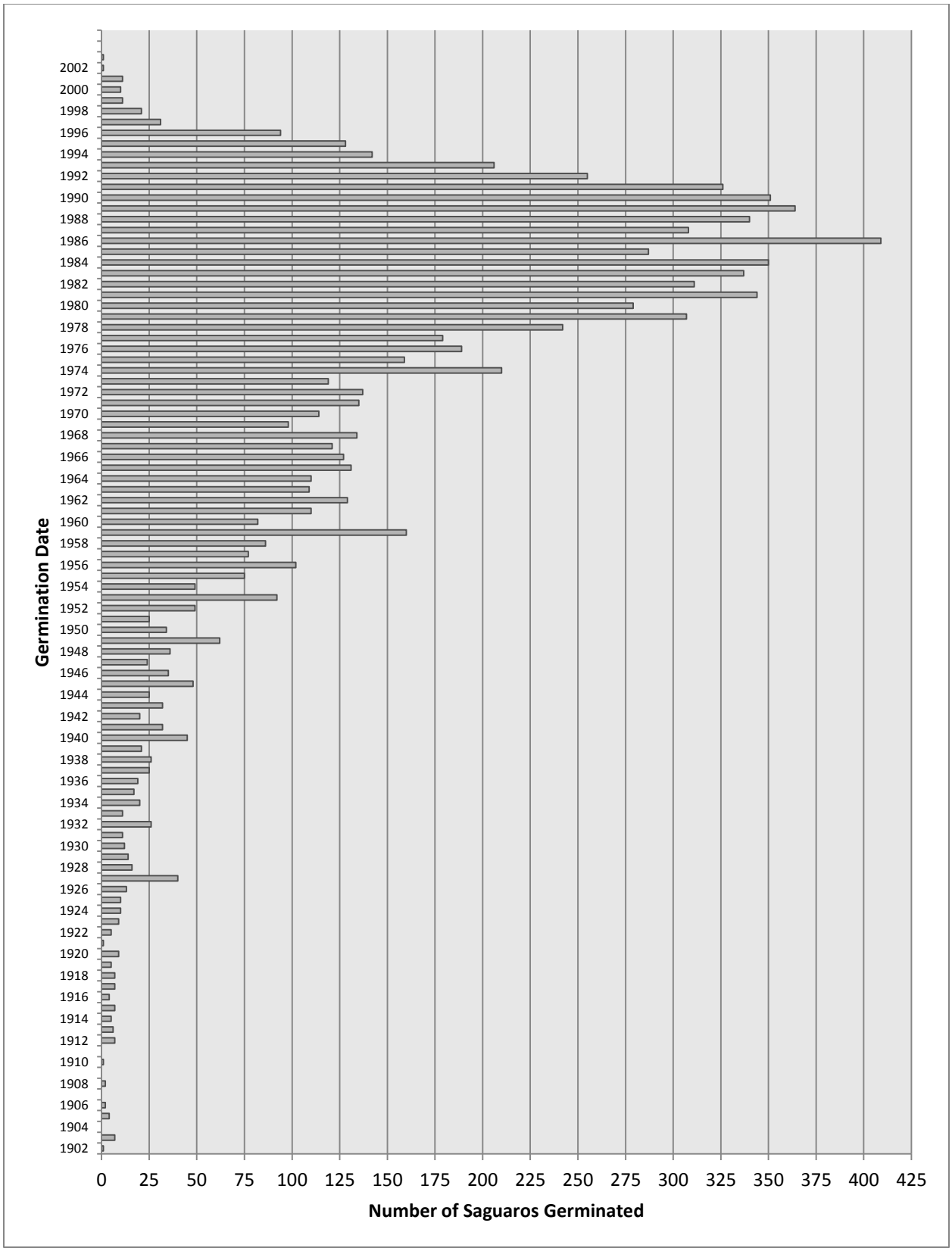


Figure 8b – Germination date for every saguaro measured during the 2012 census.

The spatial results of the census show a clear pattern that correlates with the edaphic, hydrologic, and physical features of Section 17. Most saguaros are concentrated on higher ground between the washes on well-drained, coarse soils (Figs. 9 - 11). Areas with high clay content soils, such as the Pinaleno-Stagecoach Complex soil in northwest corner of Section 17, retain more moisture and prevent seedling establishment (Fig. 11). A bowl-shaped depression near the center of Section 17 collects runoff from a wash and the slopes on either side, resulting in soil saturation and an inhospitable area for saguaro establishment as the extremely low density result indicates (Fig. 9).

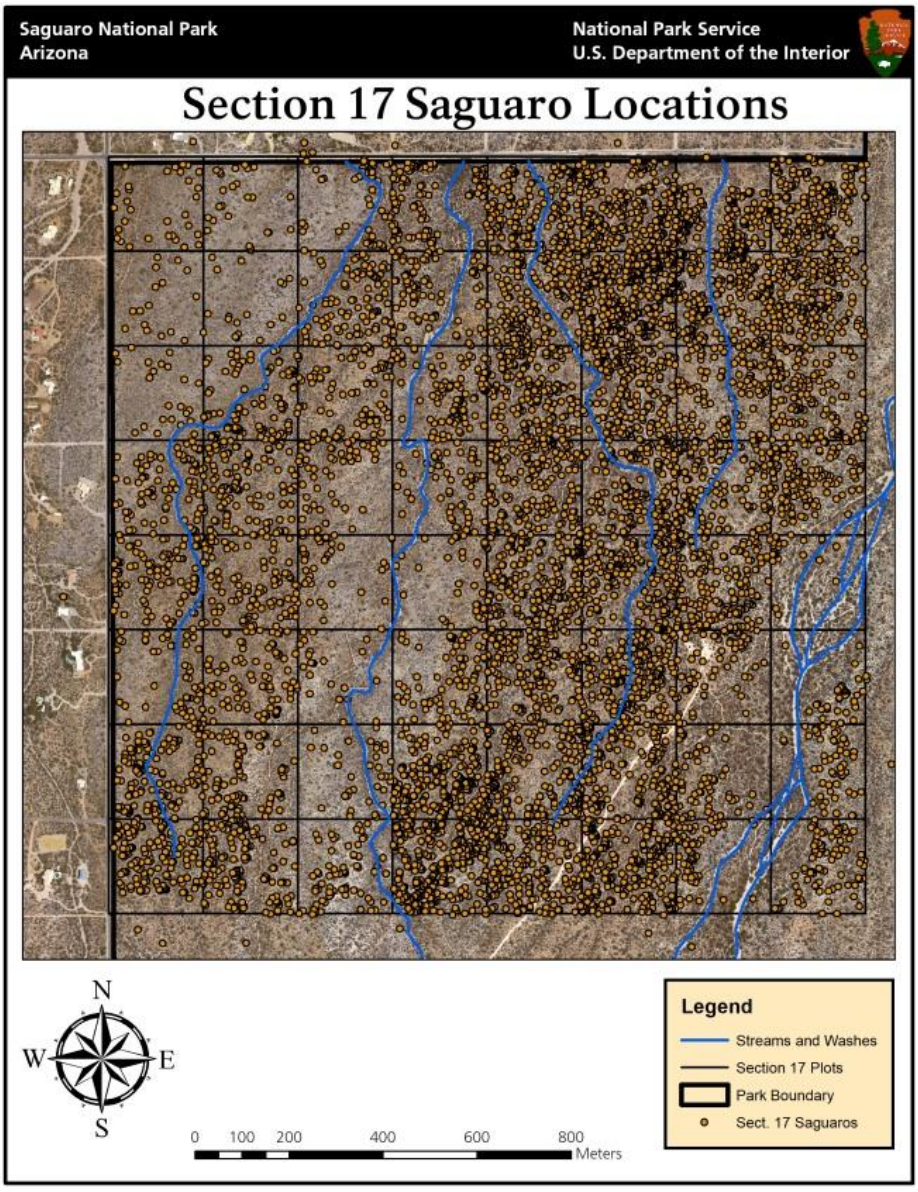


Figure 9 – Individual saguaro cactus locations are indicated by the yellow dot on this aerial photograph. Each saguaro location was determined by the use of a GPS device.

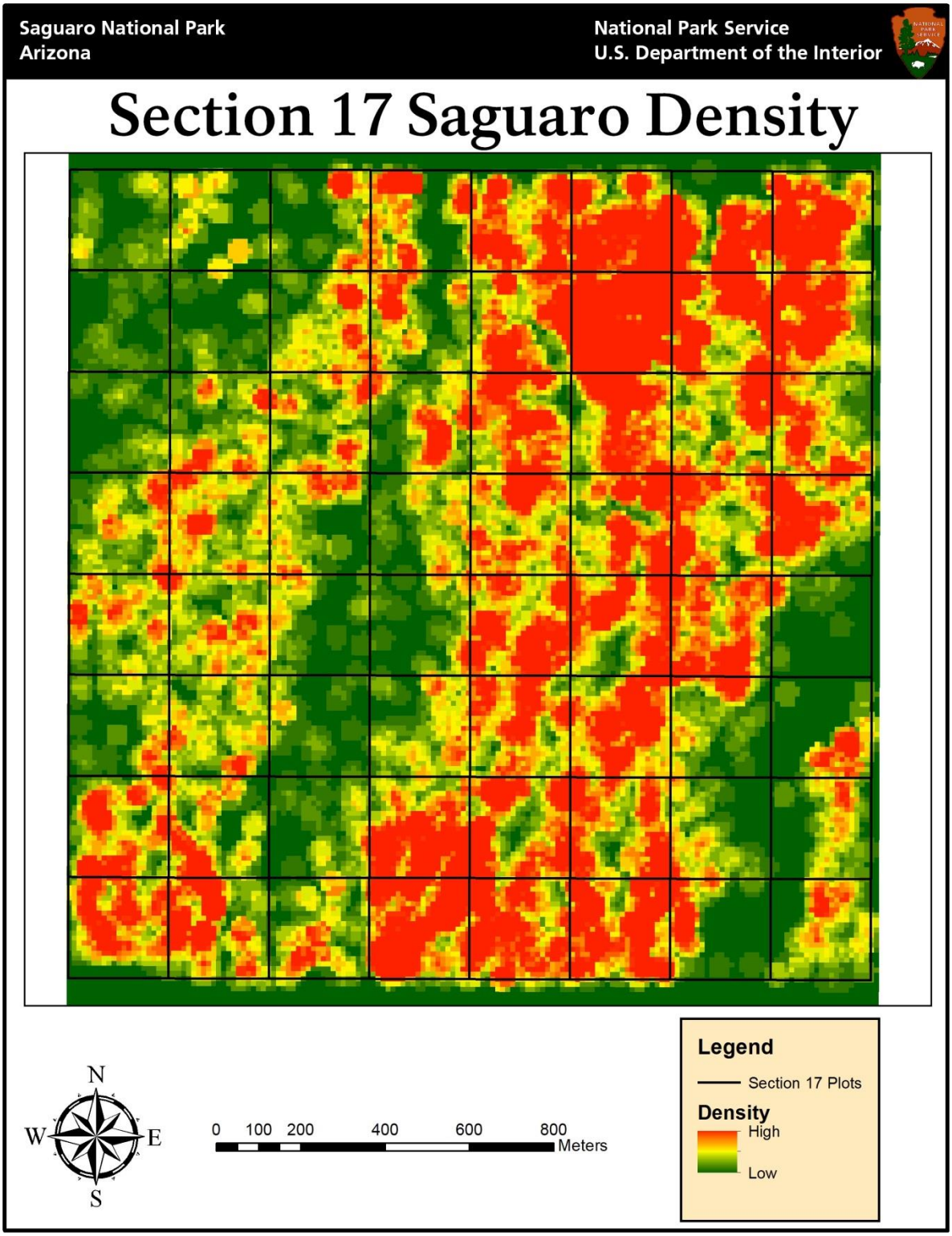


Figure 10 – The highest density of saguaro cacti are found in the eastern half of Section 17 with the exception of the large wash. High numbers of saguaro cacti are present in the southwestern corner, as well.

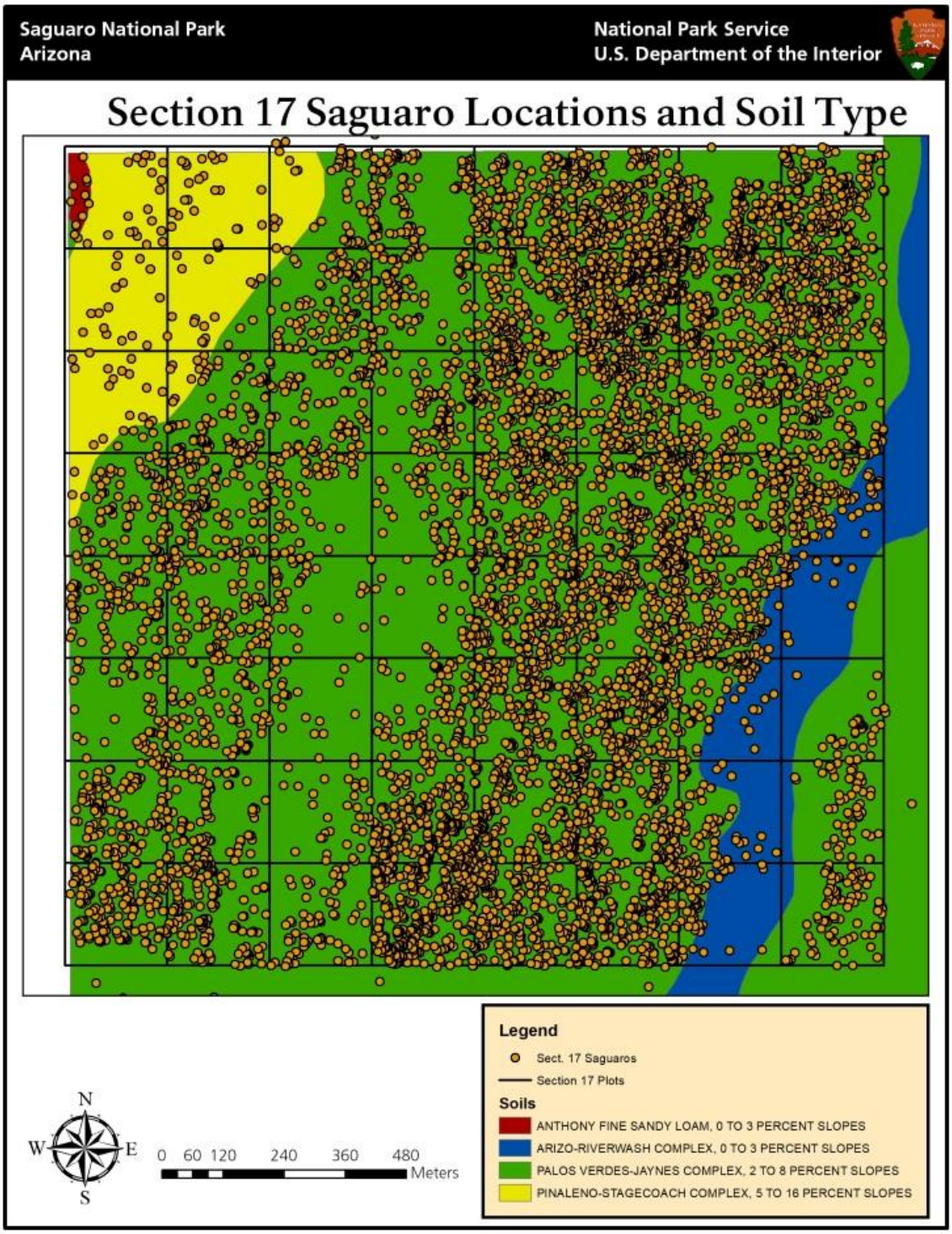


Figure 11 – The locations of individual saguaro cacti are shown with the type of soil on which they established. The Palos Verdes-Jaynes Complex comprises the majority of Section 17 and provides adequate strata for establishment and germination.

Volunteers. More than 170 volunteers, many of them high school students, participated in the Section 17 on the first day of the BioBlitz on October 21, 2011 (Figs. 12-15); another 15 volunteers joined us for the second day. Approximately 130 volunteers, including both one-day and multiple-day volunteers, but not including group volunteers, supported this project after the BioBlitz, during November 2011-March 2012. Prior to late April, when we ceased using volunteer groups due to warming summer temperatures, volunteers contributed more than 3,000 volunteer hours to the project. During summer, our Youth Internship Program (YIP) crew included several volunteers who contributed more than 100 additional volunteer hours to the project.

Education and web site. We created a website dedicated to the Section 17 project (https://sites.google.com/site/sagusection17) where volunteers and other participants could learn about the study before going out into the field, observe photos, and compare the results of their work with those of 1941 when they returned from the field. The website was updated regularly through the end of volunteer sampling in April, 2012. In addition, the Section 17 received publicity, particularly during the 2011 BioBlitz, on a number of media internet sites including National Parks Traveler, National Geographic, University of Arizona, and others, and throughout the year on the park's Facebook page. The project is also being featured in the children's book *The Park Scientists* by Mary Kay Carson, to be published in 2014.

The project spurred a number of educational programs, in addition to the many school groups that participated during the BioBlitz and throughout the year. Students from Arizona College Preparatory Academy, in addition to helping plan the Section 17 event for the BioBlitz and participated in it as part of the National Park Foundation Park Stewards Program (Fig. 12), also devoted part of their spring semester in helping study the vegetation associated with saguaros in Section 17. Meena Ravishankar volunteered frequently, and used Section 17 data to study the height and age of saguaros when they first begin to attract cavity-nesting woodpeckers; she won an award at the regional science fair for her project (Fig. 13). Park staff and interns also participated in the project (Fig. 14; Fig. 15). In addition, students from City High School, Ha:san Preparatory and Leadership School, and Sabino High School studied saguaros in and near Section 17 for educational and service learning programs during the 2012-2013 school year.

Figure 12. High school students from Arizona College Preparatory Academy sampled saguaros in Section 17 during the BioBlitz on October 21, 2011.

Figure 13. Middle school student Meena Ravishankar won an award from the regional science fair for her project on saguaros in Section 17 that focused on how old saguaros are before birds begin to build cavity nests in them.

Figure 14. Saguaro Visitor and Resource Protection Rangers John Williams and Steve Bolyard and Fire Ecologist Perry Grissom measure saguaros in Section 17 as part of an all-employee field day in February 2012.

Figure 15. Volunteer intern Siria Cerda (left), student employee Emma Fajardo, and former SCA intern Lynsey Sloat in Section 17 during the BioBlitz.

Discussion

The demographic results of this study confirm the findings of many studies completed within the past 20 years, including the major study within Section 17 that documented the decline of the original Cactus Forest and the tremendous increase in young saguaros during the decades of the 1960s-1990s (Orum et al. 2010). Other studies have documented the recruitment surge of the last 40 years in areas of Saguaro National Park outside of Section 17 (Duriscoe and Graben 1991, Turner and Funicelli 2001, O'Brien et al. 2011). The results of our Section 17 re-survey indicate that the saguaro population, as a whole, has yet to fully recover from the decline observed in the early 1940s. However, it is important to recognize that 70 years represents only approximately two generations for saguaro reproduction. In that regard, the saguaro population appears to be recovering at a surprisingly rapid rate. The current ecological trajectory and demographic pattern suggest that the saguaros in Section 17 may become more evenly distributed in age by the year 2053 in the absence of any disturbances previously discussed. During that time, we may predict that the youngest saguaro cacti in the RMD will reach reproductive age and begin to produce the third generation of saguaro cacti since the establishment of Saguaro National Park. By the fourth generation, the saguaro population has the potential to surpass the 1941 count. After 2060, visitors to Saguaro National Park may witness the Cactus Forest full of "grandfather" saguaros as seen in 1941, although the overall appearance may not be quite the same due to differences both in the ages of saguaros and in abundance of other plant species, especially trees (Appendix E).

However, there are many other factors that may determine the direction of saguaro demographics in the Cactus Forest in the coming decades. The appearance of the Cactus Forest landscape in 1941 was the result of a number of natural and anthropogenic factors, some of them unknown. Some factors that negatively impacted saguaros, such as grazing and wood harvesting, have been remedied through the protection afforded by the National Park Service. Climate variables, such as temperature and precipitation, remain well beyond the reach of management. In addition, there are other factors that have not influenced saguaro populations in the past but may in the future. This category includes increases in non-native invasive species, particularly buffelgrass, which have the potential to permanently alter the ecological trajectory of the Sonoran desert ecosystem (Stevens and Falk 2009). Although present in only a few areas of Section 17 in 2012, buffelgrass is abundant in many parts of Saguaro National Park and appears to be impacting saguaros through competition. More importantly, when buffelgrass spreads rapidly over large areas it provides a continuous fuel source for wildfire, burns exceptionally hot, and grows against the base of the giant saguaro. Saguaros are not fire adapted and a severe fire within a buffelgrass-infested area has the potential to kill every saguaro within the fire perimeter. Buffelgrass decreases the fire return interval, meaning desert fires may occur more frequently in the future than in the past.

The potential effects of long-term climate changes cannot be overlooked in any discussion about the future of the saguaro population. Climate models predict mixed effects for the future of the saguaro cactus in the southwestern United States. Saguaro National Park is located near the environmental optimum of the species' range (Niering et al. 1963, Drezner 2006) so any significant climatological change could have important implications for the distribution of cacti throughout the Park. Freezing temperatures during winter months are a primary limiting factor for the survival of saguaro seedlings (Steenbergh and Lowe 1976, Steenbergh and Lowe 1983). Most climate models predict warming temperatures for the southwestern United States on the order of five to seven degrees Fahrenheit by the year 2100 (Christensen et al. 2007, Lenart et al. 2007). Temperature increases may reduce the number of freeze events (Archer and Predick 2008) that result in saguaro mortality, however warmer temperatures increase water demands of plants during the summer months. The frequency of drought is expected to increase along with temperature over the next century (Seager et al. 2007, Archer and Predick 2008), which may have the effect of changing the limiting factor for saguaro cactus saguaro from freezing temperature to water availability.

Climate models correlate well with past observations and explain up to 95% of the variability inherent to climate systems (Bader et al. 2008), but models and forecasts do not, and cannot, fully describe the future. Some research shows that extremes in both hot and cold temperatures may become the norm and deep freezes in the Sonoran Desert are linked to the Arctic Oscillation and El Niño-La Niña phases (Guido 2011). During drier La Niña years and a negative phase in the Arctic Oscillation associated with high pressure over the North Pole, cold arctic air dips south into the mid-latitudes. Warmer polar temperatures influence the pressure system associated with the Arctic Oscillation, which may push more polar air further south in the future and lead to more freeze events and a higher winter mortality rate for the saguaro cactus (Guido 2011).

Conclusion

The saguaro population within the Cactus Forest, the primary tourist area of Saguaro National Monument in 1941, was in decline prior to the 1941 census of Section 17 due to both the highly visible mortality of many larger individuals and the less visible absence of young saguaros. The creation of Saguaro National Monument, by providing protection for the Cactus Forest, appears to have significantly improved the conditions that promote saguaro establishment. Section 17 has enjoyed this protection for more than 70 years, which is approximately half the life span of the saguaro cactus. Recovery of a long-lived species population requires patience and monitoring over time. This census study shows that much has been accomplished since 1941 and the saguaro population is significantly healthier than it was decades ago, but recovery is not yet complete. Management of the population and the disturbances that affect it must continue to mitigate the negatives and maximize the benefits to

ensure that future generations of visitors to Saguaro National Park enjoy the cactus forest landscape.

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Appendix A –History of the Section 17 Saguaro Survey in Saguaro National Park

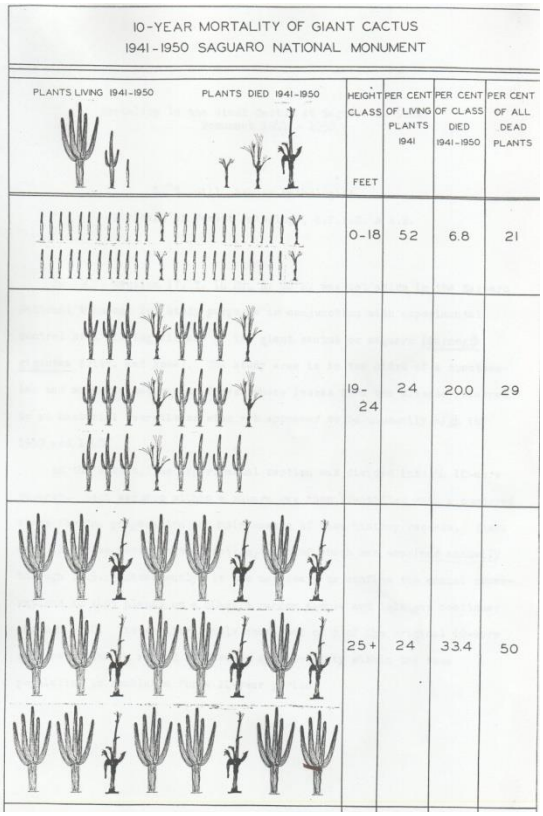


Figure from Gill (1950) showing results of the 10-year saguaro mortality study in Section 17.

Summary

In 1941, scientists studied saguaros in a one-mile-square section (no. 17 of R 16E and T 14S) of Saguaro National Park's Rincon Mountain District as part of an experiment to determine if a contagious disease was killing saguaros in the park's "Cactus Forest" area. A total of 12,898 saguaros were measured, and monitored in Section 17. Saguaros that appeared to be dying were removed from half the section, while the saguaros in the other half were left in place. After 10 years, scientists found no difference between the two areas and determined that a contagious disease was not killing the saguaros. Because long-term monitoring has continued in Section 17 since 1941, many of the records from the 1941 study have survived, including the original maps, reports, and data. In 2011, Saguaro National Park worked with school groups and citizen scientists to study long-term changes in saguaros by repeating the survey of Section 17, seventy years after the original survey in 1941.

Introduction

Saguaro National Monument was created by presidential proclamation in 1933 (it became a national park in 1994). At that time, the so-called "Cactus Forest," located in the foothills of the Rincon Mountains east of Tucson, was considered to be the finest stand of saguaros in the world (Steenbergh and Lowe 1983). However, only a few years after the Monument was established, staff and others became alarmed at a major die-off of saguaros in the Cactus Forest.

Scientists from the University of Arizona and the U.S. Department of Agriculture were called in try to understand what was causing the die-off, and if it could be reversed. In 1941, two plant pathologists with the USDA Bureau of Plant Industry, Lake S. Gill and Paul C. Lightle, began a large-scale, long-term study in a one-mile square section of the park. Gill and Lightle also studied saguaros at Organ Pipe Cactus National Monument and throughout the Arizona Sonoran Desert during this period. The section of land in Saguaro National Park, Section 17 of Range 16E and Township 14S (Figures 1-2), was the focus of intense research for several years.

In 1941 it was believed that a contagious bacterial disease may be responsible for the death of the saguaros, which were observed to be oozing a black fluid prior to dying. The main experiment in Section 17 was to test whether removing the diseased individuals would result in a higher survival of those that showed no signs of the "bacterial rot" disease, but the project gathered a significant amount of data on saguaros that continue to serve the Park to this day.

Study design

In the winter of 1941-1942, every saguaro in Section 17 was ranked according to height, examined for disease, numbered, and marked with a wooden stake. Each saguaro visible in an aerial photo was also mapped (Figure 2). In all, 12,898 saguaros were recorded (Gill 1950).

To experimentally determine whether removing the diseased saguaros would increase the survivorship of those that showed no signs of the disease, Section 17 was divided into treatment control areas. In the northern half of the section, all saguaros were left alone, and simply monitored. But in the southern half of the section, all saguaros that showed signs of disease were removed by park staff working with Gill and Lightle (Figure 3). The giant cacti were pulled down, sawed into small sections, transported to a pit where they were fumigated with a mixture of kerosene and paradichlorobenzene (a pesticide), and buried (Gill and Lightle 1942; Figure 4).

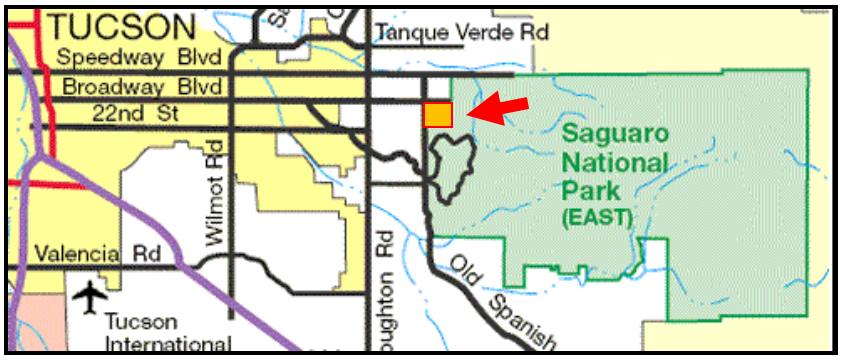


Figure 1: Location of "Section 17" (indicated by orange square), Rincon Mountain District, Saguaro National Park.

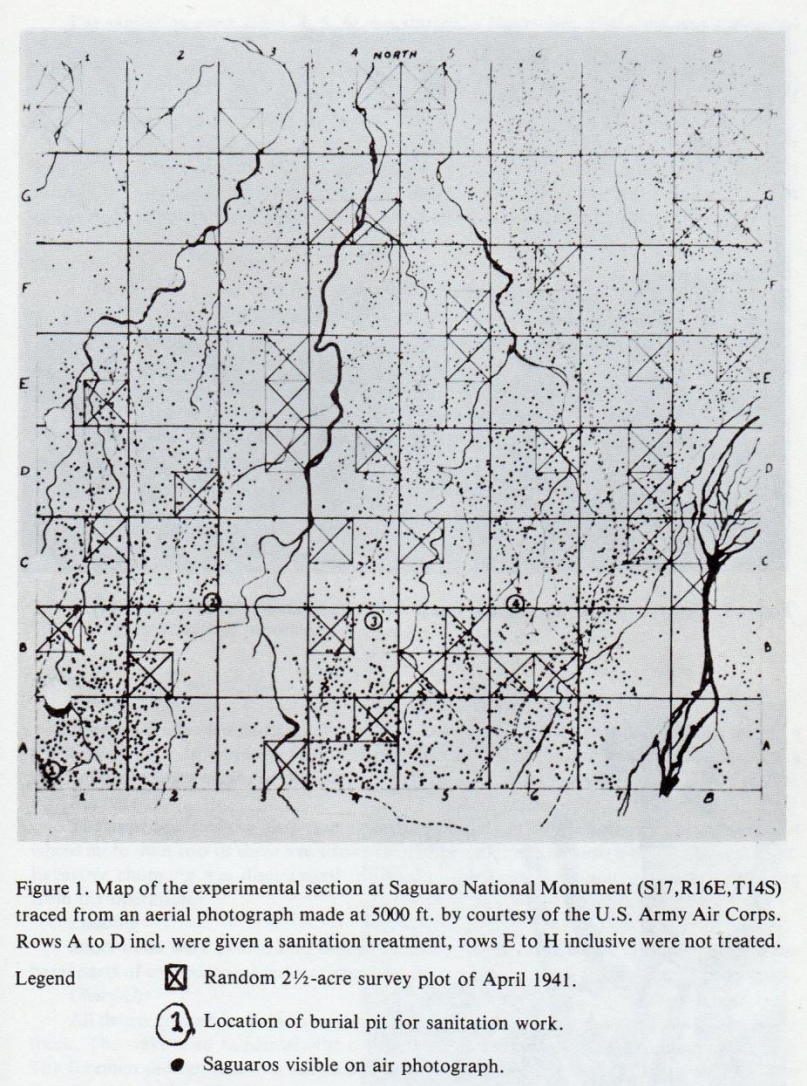
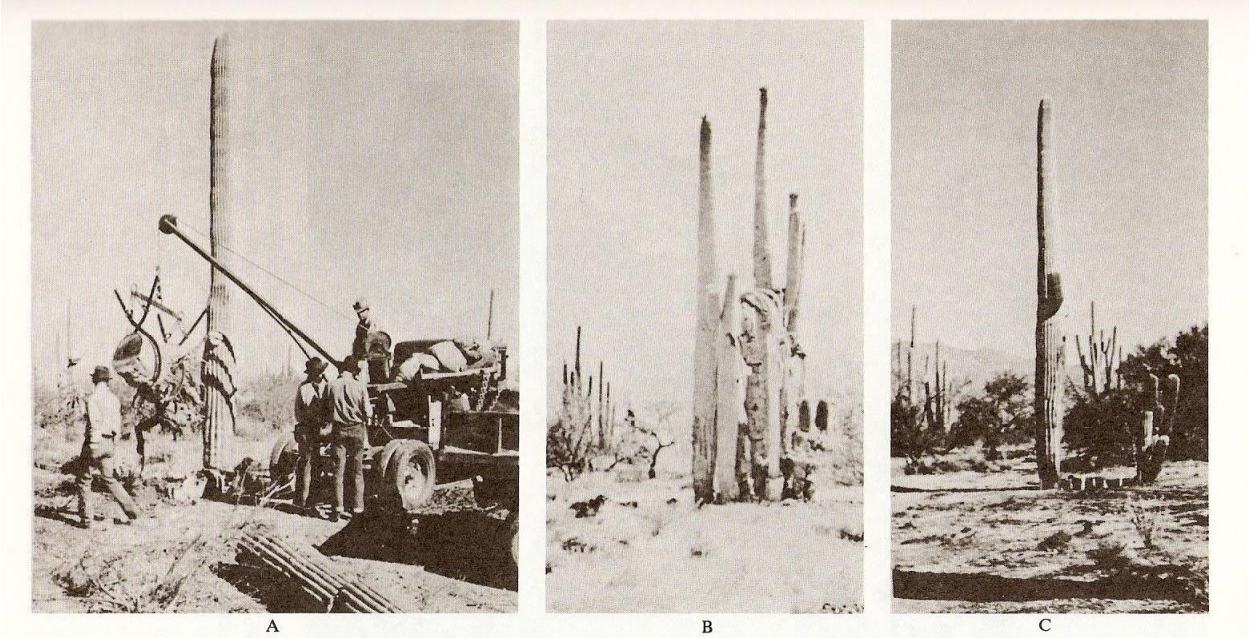


Figure 1. Map of the experimental section at Saguaro National Monument (S17,R16E,T14S) traced from an aerial photograph made at 5000 ft. by courtesy of the U.S. Army Air Corps. Rows A to D incl. were given a sanitation treatment, rows E to H inclusive were not treated.

Legend
Random 2½-acre survey plot of April 1941.
Location of burial pit for sanitation work.
Saguaros visible on air photograph.

Figure 2. Map of Section 17 (reprinted from Steenbergh and Lowe 1983). Each dot represents an individual saguaro. Dark irregular lines are washes.



A B C

Figure 5. A portable crane with iron tongs was used to load the heavier butt cuts and stumps (A) and was helpful in removing diseased cacti from group (B) without damaging the healthy members of the group (C).

Figure 3. Photos from the original report (Gill and Lightle 1942, reprinted in Steenbergh and Lowe 1983), showing methods for removing diseased saguaros from the southern half of Section 17.

Figure 4. Diseased saguaros were cut into pieces, hauled to pits, doused with kerosene and pesticide, and buried. Photo source unknown.

Although the original intent of the experiment was for saguaros in the southern half of the section to continue to be removed as they showed signs of the disease, this was not done due to labor shortages during World War II (Gill 1950). However, all cacti in Section 17 were monitored as planned for 5 years, and a subset were monitored for 5 more years.

Results, 1941 – 1950

Data collected on the 12,898 saguaros mapped and monitored in 1941 were published by Gill and Lightle (1942) and in a slightly different format by Steenbergh and Lowe (1983). The largest number were between 12 to 18 feet in height, and the great majority were over 12 feet tall (Figure 5).

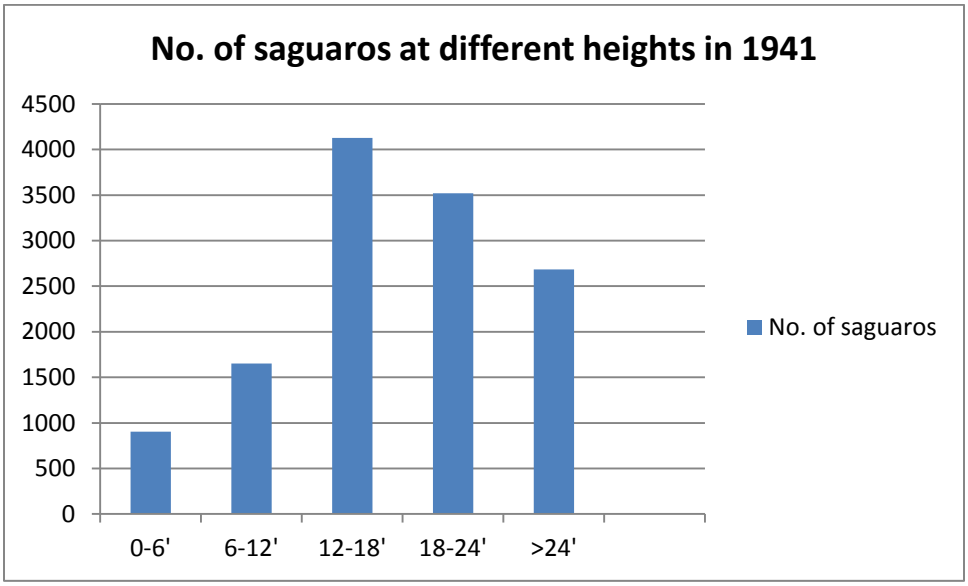


Figure 5. Heights of 12,898 saguaros in Section 17 in 1941. It is not completely clear in the results how Gill and Lightle classified saguaros by height class (they used 0-6', 7-12', etc., and nowhere do they address how they classified plants that were, for example 6.5' tall). Steenbergh and Lowe (1983) interpreted these height classes as 0-6.99, 7-12.99, etc. However, Stanley Alcorn, who inherited other monitoring plots from Gill and Lightle, used the 0-6, 6-12 height classes on his plots (Tom Orum, personal communication). We use Alcorn's interpretation, which seems more likely.

A preliminary report on the Section 17 study (Mielke 1944) indicated that while results of the control work appeared encouraging, other research was beginning to indicate that the disease was not contagious, but rather caused by a bacterium that was possibly carried by a moth. In addition, Mielke (1944) suggested that wood-cutting and over-grazing were major factors in the decline of the saguaro, which did not appear to be reproducing in the Cactus Forest.

However, in 1946 Gill and Lightle compared the results from the entire section through 1945 and found no significant difference was found in the survival of cacti in the southern vs. the northern

halves of Section 17 (Figure 6). Although they expressed uncertainty about the implications of the research, a few years later Gill (1950) reported that results over the 10 full years of data on the six monitoring plots were consistent with the conclusion that the disease did not appear to be contagious. Although Gill was disappointed that the experiment could not be carried out as originally planned, with continued removal of diseased saguaros after 1941, he concluded that "rot" did not appear to be a disease that threatened to wipe out the saguaro as a species. He noted that mortality increased with the size of the plants and like Mielke (1944) pointed out that the continued lack of reproduction in the Cactus Forest was a major problem (Gill 1950).

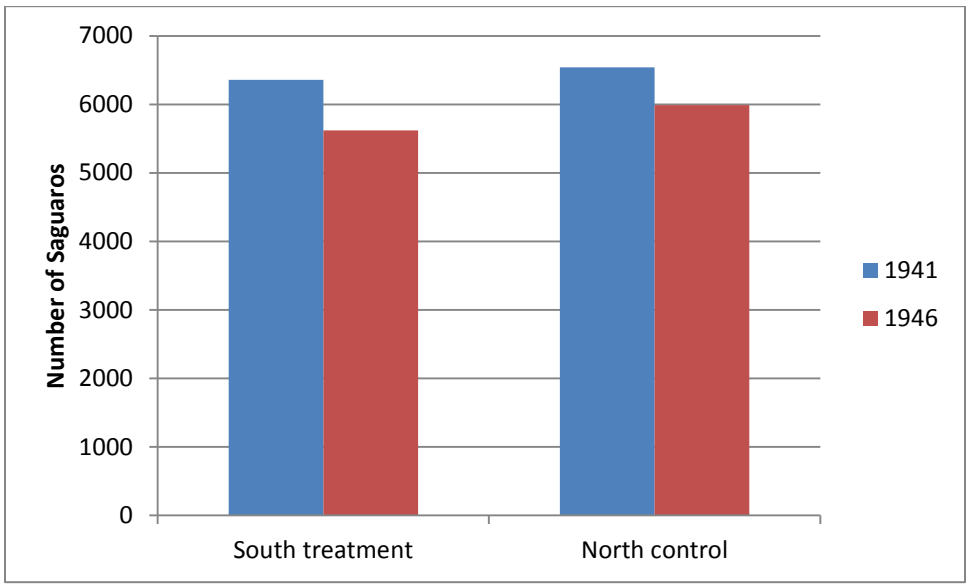


Figure 6. Number of living saguaros in Section 17 showing results of Section 17 saguaro experiment, 1941-1946, based on Table 1 in Gill and Lightle (1946). Removal of diseased saguaros did not increase survival of healthy ones remaining; indeed, more saguaros survived in the northern, control section.

Continued research on saguaros, 1941-present

Due to the negative results of the Section 17 experiment, attention turned to other potential causes of the decline of saguaros in Saguaro National Park. The decline continued for several decades (Figure 7) until the population began to show clear signs of rebounding in the early 1990s. Research in the 1950s focused on the disease called bacterial necrosis and potential insect vectors, while in the 1960s and 1970s the focus turned increasingly to ecological factors such as the relationship between saguaros and nurse trees, the role of rodent herbivory, and the importance of climate, particularly freezing weather (see McAuliffe 1993, Ahnmark and Swann 2009).

It is noteworthy that, after Gill and Lightle completed their study, the 6 plots subsampled during 1946-1950 continued to be monitored annually – first by Stanley Alcorn, plant pathologist at the University of Arizona, and then by his research technician, Tom Orum, and Nancy Ferguson. These plots also formed the basis of many University of Arizona-based research studies. As of 2013, Orum and Ferguson are continuing to collect data on the 6 plots (Orum et al. 2010) in one of the longest monitoring studies conducted in any national park.

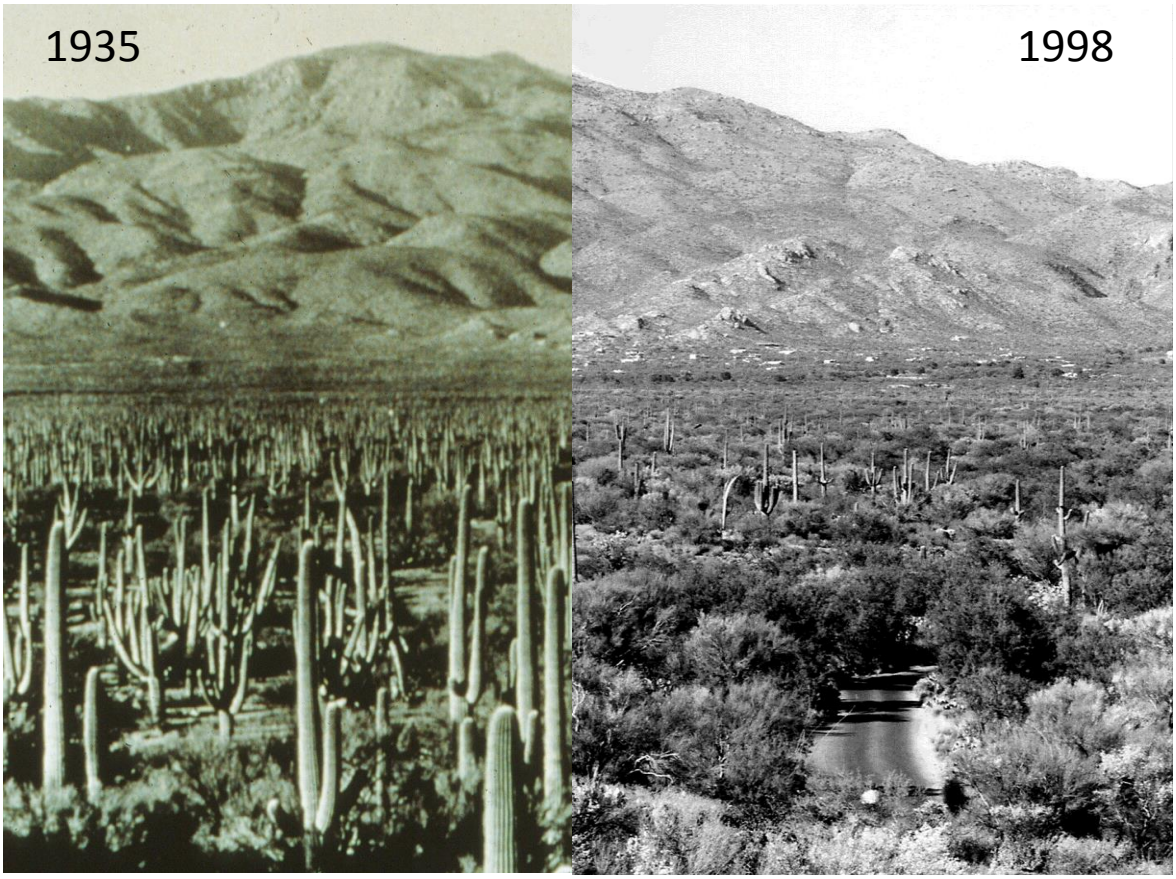


Figure 7. Montage of two photos showing the Cactus Forest, Section 17 area, in 1935 and 1998. Note not only the dramatic loss of large saguaros, but also the increase in nurse trees during the period; young saguaros are currently growing beneath many of these trees.

In retrospect, it appears likely that the immediate cause of the die-off of saguaros in the Cactus Forest in the late 1930s and early 1940s was the delayed effects of two intense freezes in 1937 and 1939. Saguaros are sub-tropical plants that cannot tolerate freezing weather, and older plants are particularly susceptible to freeze. After many years of the wood-cutting (which removed the saguaros' protective "nurse trees") and cattle grazing (which killed young saguaros due to trampling), the Cactus Forest was dominated by older, larger plants that were dying in large numbers. The black fluid they were oozing as they died appears to have been, in many cases, a secondary effect of tissue damaged by freezing, not disease. Similar die-offs were seen (and

studied) after freeze events in the 1970s (Steenbergh and Lowe 1983), and older saguaros now also appear to be dying as a result of the deep freeze of February, 2011.

Also, Mielke (1946), Gill (1950), and many other researchers noted, the Cactus Forest was missing the most important age class of saguaros – the younger ones. As older individuals died in the 1940s, most were simply not being replaced. Gill (1950) predicted that the small classes of saguaro would be "practically non-existent by 1980" in the Cactus Forest.

This prediction was largely correct, but since 1980 a significant change has occurred. Beginning in the 1990s (Turner 1992), scientists began to see a large increase in the number of saguaros in Section 17 and throughout the Cactus Forest – younger individuals, now surviving under the palo verde and mesquite nurse trees that began to flourish after Saguaro National Monument was created, probably due to the protective policies of the National Park Service. Survival of young saguaros surged during the rainy years of the 1980s and early 1990s (Orum et al. 2010, O'Brien et al. 2011). Although this great increase has slowed since, it seems possible that the number of saguaros living in Section 17 is beginning to approach what it was in 1941. However, saguaros are very slow-growing, and the resurgence of the Cactus Forest cannot be seen on a landscape scale (Figure 7). An individual that germinated from a seed in 1970 is about 8 feet tall, and still hidden in the branches of its nurse tree.

The intensive study of saguaros in Section 17 provides Saguaro National Park with a great opportunity to study ecological change in the park's Cactus Forest. In repeating the 1941 survey during 2011-2012, seventy years after the first survey, we were interested in these questions, including: How many saguaros are there in Section 17 today? How have the demographics of the population changed? Will the Cactus Forest someday resemble what it looked like when Saguaro National Park was created, and if so when?

Appendix: Notes on 1941 data sources and detailed methods

We are fortunate that much of the original data and many details and reports from the original Section 17 study have survived. In 1983, a number of documents that were held at Saguaro National Park were preserved by NPS scientist Warren Steenbergh and published in the *Ecology of the Saguaro* series that he co-wrote with University of Arizona professor Charles Lowe (Steenbergh and Lowe 1983). Although the location of the original photographs is unknown, the park possesses a copy of the original map of the saguaros in Section 17 (copies in Resource Management office and at the Western Archeological Conservation Center). The original log books, with the records for all of the 12,898 saguaros, have been preserved by long-time saguaro researchers Tom Orum and Nancy Ferguson, who have generously provided the park with a copy.

Prior to the experiment, beginning in 1940, engineering students from the University of Arizona divided Section 17 into a total of 64, 10-acre blocks. Each corner was marked by a wooden stake. In September, 1941, work began on collecting data on all saguaros in the section. Every living saguaro was identified with a wooden numbered stake. The numbers started with No. 1 in the in the Southwest corner of each 10-acre quadrat, and progressing in north-south strips to the east edge of the quadrat.

Data collected on saguaros in southern half of Section 17 coincided with the removal of diseased saguaros on this half between November 1941 and January 1942, and continued through March 1942 on the northern half. Data collected on each cactus included height to the nearest 6 feet; serious mechanical injuries, if any, due to removal of nearby diseased saguaros; extent and degree of disease condition; and misc. notes. The data were recorded in the log books. It is not reported what method the researchers in 1941 used to measure height. Following the original establishment of the study, all saguaros were examined annually through 1945, and notes were made regarding their disease condition or death. Between 1945 and 1950, these notes were only made on a subsample of 6 of the original 64 blocks.

At some point during 1941, large saguaros were recorded on a map (Figure 1) that was traced from an aerial photograph taken from 5000 feet by the U.S. Army Air Corps. Different versions of this map exist; on the version published by Steenbergh and Lowe (1983), the burial pits, main plots, and subplots are clearly marked. Unfortunately, because the saguaros on the map are not numbered it seems unlikely that we will be able to locate, with certainty, those that have survived until today.

The 6 plots used to monitor saguaros during 1945-1950 (Gill 1950) are the same ones now monitored by Tom Orum and Nancy Ferguson (Orum et al. 2010). Gill and Lightle (1942) also established 6 smaller plots in Saguaro National Monument; two of these are in Section 17. These plots have been re-surveyed 3 times: in the 1970s, 2000, and 2011 (Steenbergh and Lowe 1983; Funicelli and Turner 2002; Saguaro National Park, unpublished data).

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Appendix B - Survey Protocol for Saguaro Census

(January 8, 2011)

Supplies and Equipment

- Park radio
- Digital camera for recording field data and volunteer photos
- 1-2 extra park radio batteries
- Emergency contact sheet (radio, phone numbers)
- Large crew first aid kit
- GPS Garmin unit
- Clipboards with volunteer forms
- Plot maps with UTMs of corners
- Leader's binder with safety topics to cover, extra volunteer forms and data sheets, list of UTM plot coordinates, census calendar, and *How to use a clinometer* worksheet
- Orientation poster (for interpreting why we do the Census to volunteers)
- Pin flags to mark saguaros – up to 200, numbered (e.g., A-1, A-2…Z-99)
- Pink and blue boundary flagging
- Gatorade and extra water
- Complete census equipment bags (see below) – one for each 3-4 person group

Census Equipment Bag Contents

- 1-2 clinometers
- 2 wooden stick measures
- 1 metal tape measure
- 1 20-m roll tape
- Clipboard with plenty of data sheets, map and coordinates of plot
- 1 two-way radio
- Extra batteries for two-way radio
- Writing implements

Figure 1. Metal tape measure (left), clinometer (center) and folding rule (right)

Safety

Please refer to two documents from the 2010 Saguaro Census: the Safety Plan and the Green-Amber-Red review, which is an attachment to the Safety Plan. These lay out many of the safety concerns that are relevant to the Census and working with volunteers. The Saguaro Census has some inherent safety concerns that must be addressed – take them seriously!

Recruiting Volunteers and Selecting Plots

In 2010, when contacting new volunteers or volunteer groups, we explained how difficult the Census work was. We requested that they describe their physical ability and experience hiking in the desert (see Safety Plan for more information). We explained in detail what is involved in the Census, including safety, the difficulty of the terrain, need for the right clothing – hats, good boots, and long pants required! For individual volunteers, we invited them to join an easy plot first and monitor how well they do. Then, if they were interested in more challenging plots, we would progressively take them to more difficult plots. When receiving RSVPs for Census dates, we established a cut off point for each plot, typically about 15 volunteers for "public" plots, or about 5 more for groups (beyond this number, confusion begins to reign!). In 2010, we had a single intern, Kimberly Diamond, in charge of recruitment, volunteer organization, documentation, and logistics with the project manager (Don Swann). Kim usually went out with volunteers, accompanied by other park staff (Don Swann, student employees, or other experienced staff).

Groups ranged in ability, but nearly all were recruited because of their outdoor experience. We used groups from local hiking societies, the Friends of Saguaro National Park, the Summit Hut, the Sky Island Alliance, the University of Arizona, and many others.

Each month in 2010 we surveyed a variety of plots, ranging from easy to difficult, in both districts of the Park. In 2010, the last Saturday of each month was considered a 'public plot' for individual volunteers – for this, we selected one of the plots at RMD that was easy enough for all levels of physical ability. At the beginning of the month an email was sent to all census participants that described the plots in terms of whether they were easy, intermediate, or difficult. Based on this email, volunteers could determine if they were capable of participating in the plot surveys. Very difficult plots were left off the mass email, but we would invite individual volunteers that we believed, based on our experience in working with them, were fully capable of the physical work. Plot difficulty assessments were based on distance from road, slope, vegetation, and number of saguaros during last survey.

Flagging the Plot

Pre-flagging is important so that the plot can be scouted out in advance. Pre-flagging helps make the day of the Census go much faster and smoother. Pre-flagging also provides an opportunity to determine where parking should occur, the easiest route to hike to the plot, and what type of terrain to expect. We recommend pre-flagging the plot before the day of the Census, but no more

than a week in advance. We also made a point to let the rangers know that we had flagged a plot, in case a question about it came up.

If the plot is off-trail, flag a route to the plot using flagging other than pink or blue. Take a radio, extra battery, plot map, pink and blue flagging and other flagging color if necessary. One of the appendices of the Saguaro Safety plan is a data sheet for flagging the plot.

To flag the plot, we recommend the following steps:

1. Locate one corner of the plot using GPS. Ideally, locate the corner stake.
2. Flag the corner with pink and blue flagging.
3. Using the view on the GPS unit that shows the coordinates, follow the north-south coordinate to the next corner (200 meters). Every twenty meters or so, tie a pink flag on a shrub (consider using Velcro or other easy-to-remove tape in future). In brushy areas, flag more frequently than every 20 meters.
4. We recommend a knot that can be easily removed with one hand. Put the flag high enough so that it can be seen, but not so high that it cannot be easily removed. Avoid flagging cholla.
5. There will be some drift in the GPS coordinate. Follow it anyway, and adjust the flags slightly if one is way off. GPS drift is random and there is no need to create an absolutely straight line.
6. When you arrive at the next corner, find the corner stake. Flag the corner with pink and blue flags.
7. Follow the east-west coordinate to the next corner, flagging in pink every 20 meters.
8. Continue until the entire plot is flagged.

Before the Volunteers Arrive

Check RSVPs and prepare a list of the volunteers that are attending. Once the list reaches 15, do not allow more volunteers to sign up. Sign out a park vehicle for the census date. Gather all equipment the day before, and load the park vehicle the morning of the census. Send an email to law enforcement rangers notifying them of the date, location and contact persons for the census for that day. In addition, provide law enforcement and a fees or visitor center employee a copy of the plot map and emergency contact info, and post this in the Resource Management office. The plot maps can be found under *P:/Resources/Saguaro 2010/Maps and data,* and are in a PowerPoint document titled *Plot finder maps*.

For each public saguaro census, there should be at least two park staff members/interns, or one park staff/intern, and one very experienced volunteer to lead the volunteer group. The Census seemed to work best with about 5 groups of 4 people each, with one experienced person in each group and one "roving supervisor," usually one of the leaders, who roamed around the plot to check in with groups, take photos, check data quality, make sure the groups stayed on track and did not get separated, and answer questions.

Orientation to Volunteers

Staff members/interns should arrive early in the park vehicle to meet the volunteers at the visitor center. Once everyone has arrived (in 2009-2010, we usually started at 7 AM until December, then 8 AM until April), have one of the park staff or interns provide an orientation about the census. Orientation should include a greeting/introduction, brief history, explanation of how the survey is conducted, a safety message, and a check to ensure that everyone has enough water and food. We used a stiff poster board with repeat photos of the Cactus Forest and simple data graphs of previous results to interpret changes in the saguaro population in the park over time during the orientation, and this is also a good time to show pictures of small saguaros and demonstrate equipment operation.

Drive to the plot – we usually carpooled, with several of the volunteers driving, and with one park vehicle. At the parking spot, we divided the gear to carry to the plot. One staff member/intern should lead the group (preferably the person who flagged the plot) to the plot. The other staff member/intern should remain at the back of the group to make sure no one gets lost or lags too far behind.

Surveying the plot

1. *Training*. Once the plot is reached, a detailed training is essential. It is easiest if this is done in groups of about 4, with an experienced leader in each group explaining the procedures. If this is not possible, it is best to do an orientation with the larger group. The orientation should cover:
    a. How to identify a small saguaro compared to other cacti
    b. How to measure a saguaro using a tape measure
    c. How to measure a saguaro using a clinometer
    d. How to record data
    e. Other important "census rules" (see below)

2. *Moving through the plot*. Once the groups are trained, the leader will spread them out along a boundary line, approximately 20 meters apart. The groups will walk together in their designated swaths, and count and measure each saguaro within their group's boundary (see figure 2). How wide the swaths are will depend on how dense the saguaros are, and very dense plots will go better if the swaths are less than 20 m wide.

    As an example: One group will start in the northwest corner and follow the boundary flags 200 m east to the northeast corner. The next group will start 20 meters south, and follow a 20 m wide swath 200 m east to the eastern boundary line. The next 2-3 groups will do the same. *An experienced person in the most southern group will follow a GPS coordinate designed by the leader and flag the bottom line of the section of the plot that being sampled.* This line (southern line in this case) will form the northern boundary of the second half of the plot in a "typical" plot where the plot can be covered in two sessions; plots with many saguaros will need to be broken into 3-4 sections.

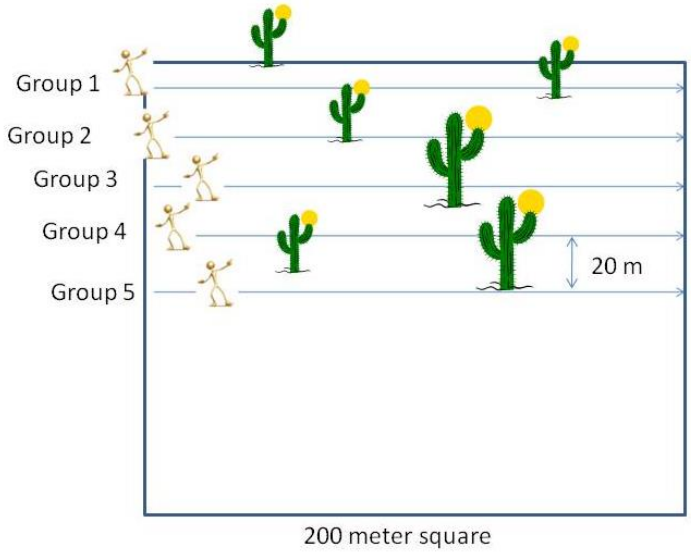


Figure 2. Illustration of a Saguaro Census plot, showing how 5 survey groups of 3-4 people move across the plot. Typically, the top group will follow the northern flag line from the northwest corner to the northeast corner, a distance of 200 meters. They will measure and flag all saguaros as they go. Group 2 would measure and flag all saguaros in a swath about 20 meters wide, working parallel to Group 1. Group 3 would work a 20 meter swatch parallel to and just south of Group 2. Group 4 would work south of Group 3, and Group 5 would work south of Group 4. A person in Group 5, or the roving leader, will flag a temporary southern boundary of the plot. Often the temporary southern boundary would be 100 meters south of the northern boundary and through the middle of the 200 x 200 m plot, but this will vary depending on how dense the saguaro population is on the plot.

3. *Sampling*. In a group of four, there is typically a recorder, two people estimating saguaro heights using a clinometer, and one person looking for and measuring small saguaros. Once a saguaro is encountered, it is flagged with a numbered pin flag and measured, and the arms and holes are counted. All of this data, including the pin flag number (flags are numbered to avoid double-counting saguaros; numbers are recorded so that we do not forget to flag any saguaro), is recorded by the recorder. Saguaros can be directly measured using a tape measure, and the only trick is to make sure they are measured in meters, *not* inches or centimeters. Even very small saguaros should be measured in meters. See "Census rules" for measuring.

   For estimating the height of taller saguaros, clinometers were used in 2000 and 2010 (and presumably 1990 as well). Two people should always independently estimate the height. See the Census rules.

4. *Checking the work*. Walking a 20 meter wide swath that is 200 meters long, measuring every saguaro, will often take a couple of hours. This is usually a good time to take a break if one has not been taken. When the groups reach the end, we then switch them. For example, the 5th group could walk down to where the 1st group was, and then everyone else can bump up 20 meters. The main point is that the groups will all walk back through a different area than the one they sampled, looking for any saguaros the first group missed. And yes, it is a contest! The goal is to look hard and find new saguaros (or cacti that are not saguaros and must be removed from the first group's data); walking back we have more time, new lighting, and a new perspective.

   If any new saguaros are found, they are flagged and measured as before. The recorder makes a note that they were found on the second pass, such as by marking them with an asterisk and a line. Then, a line should be put below this section also before starting another transect. The second pass does not usually take more than 20 minutes.

5. *The third pass to pick up all the flags*. This usually takes about 10 minutes. On the third pass we do not look for new saguaros, and do not measure one if we find it unless we are ABSOLUTELY convinced that someone before us has not removed the flag. On the third pass all the side and corner flags are picked up as well except, of course, the side that will become the new boundary of the rest of the plot. If we thought we might have a hard time finding our way back to the start, we might leave those flags up too.

6. *The second half of the plot*. This proceeds similarly to the first half. On plots with many saguaros, of course there may be thirds, or quarters, or other divisions. On the most difficult plots in 2010, we used a large crew (more than 20) for 3 or more days.

7. *Closing out*. At the end of the day, all flags should be removed from the plot unless the plot is not yet done. We generally provided cold Gatorade to all volunteers when we returned to the vehicles. We took a group photo and thanked everyone! Additional information on closing out is in the Safety Plan.

8. *Data entry*. Data should be entered as soon as possible when the field work is completed – preferably the same day. All data was entered into an Excel spreadsheet and then checked by a second person.

Census "rules"that everyone should know

* Measure to the top of a saguaro's spines, not the green fleshy part.
* A saguaro is considered a double or triple if two or more saguaros appear to be connected, or are sharing the same base. (In the case of a double saguaro, measure the

stem of the tallest "saguaro", count the other stems as arms, and make the note "double" in the notes).

* A bird hole is defined as a very dark, circular hole in a saguaro that an animal/bird may live or nest in. A bird hole looks different than a scar or irregular hole.
* If the main stem of a saguaro is missing/broken-off, but has arms that exceed the height of the main stem, measure to the top of the broken-off stem and note "broken stem" in the notes.
* Make sure to count every saguaro arm, no matter its location or size. Small nubs where the arms are just emerging from the stem or other arms are still considered arms.
* Some saguaros have arms growing on other arms. Each arm should be counted separately.
* The flags that form the sides of the Census plot create an imaginary line that outlines the plot. These lines will be slightly erratic because of natural "drift" in the GPS unit, but the drift is random. To determine if a saguaro is "in" or "out" of the plot, sight from one flag down to the next one in a straight line. If the saguaro is inside the line, or on it, count it. If the saguaro is outside the imaginary line, it is not counted.
* Do not count dead saguaros. However, count any saguaro that still has green on it and is still standing (not green saguaros lying on the ground). If you see a live or dead saguaro that has a tag with a number, however, record the number and indicate if dead.
* ALWAYS have two people use the clinometers to estimate height. The proper procedure is to have one person measure the saguaro, calculate the height, and keep the result to him or herself while the next person measures. Then, the two share their results. If the estimates are within 0.1 m (or 0.2 m for a very tall saguaro), they split the difference. If they are further away, they re-take the measurements until there is agreement.

Issues to be on the look-out for

Recording data: It is important that the data recorder write legibly and that they fill out all columns. To ensure data quality, the folks measuring saguaros usually call out the height, and the recorder calls it back as he/she enters it – very important for ensuring accuracy.

It is VERY important that the date and plot number be recorded on every data sheet (leaders could record the date and plot prior to sampling if desired). It is also important that the data recorder fill in the names of all of the workers and follow the other instructions on the data sheet. The roving supervisor should periodically check the data for each group to make sure that the form is being filled out correctly and is legible. At the end of the day, the leader should ensure that the data forms are intact and properly stored.

Estimating height: It is important the person who teaches the others in the group be very experienced in how to estimate height using a clinometer. The roving leader must check in at least once with each group and measure a saguaro or two with them to make sure the group is doing it correctly. Early in the season in 2010 we did not ensure this and we found a few differences in people's opinions about how it should be done.

There are detailed instructions on how to use the clinometers on the instruction sheet. The most common mistakes are:

a. Adding the two numbers incorrectly.
b. Reading the wrong (left) side of the clinometer.
c. Measuring 10 feet instead of 10 meters from the saguaro.
d. Standing on a slope, so that the base of the saguaro is above the measurer's eye, or the top of the saguaro is below the eye (this can be accounted for, but requires subtraction rather than addition and can be confusing to staff and volunteers).

Some of our measuring devices have both metric and English units, and ensuring that metric units are used is an important part of the orientation.

Figure 3. Using a tape measure and clinometer to measure a saguaro. It's easiest if you are on same contour as the saguaro, and not looking into the sun. Always have two people measure independently!

Figure 4. Using a folding rule to measure a saguaro. You can usually measure up to a 4 meter saguaro this way, especially if someone else lets you know when the stick is at the top.

Saguaro Identification

It's important to do a bit of training on this starting out and to make sure volunteers know to ask questions when they find what they think is a small saguaro. Develop and visuals before the season if possible, and use them. The most important things to note are the following:

1. Saguaros always have straight spines (barrel and pincushions have curved spines).
2. A small saguaro (less than a foot or two) is rounded at the top, narrows at the bottom, and resembles the shape of a thin hot air balloon.
3. A very small saguaro (less than an inch) may look different than a small one; it is more globular.
4. Saguaro spines are almost always white. Hedgehog cacti usually grow in clumps, are shaped like a cylinder (not narrow at the base), and have brown or golden-brown spines.
5. Very small hedgehogs can have single stems, and distinguishing them from saguaros can be tricky. Fortunately, this is rarely an issue, but it is occasionally. Look for the shape and spine color. In the rare occasion where confusion persists, take a good photo and record the pin flag number, and submit to an expert back at the office. Don't guess!

It is always a good idea to bring everyone over to inspect the first very small saguaro you find, and the first single stem hedgehog. This helps in the training.

Appendix C – Section 17 Volunteer Brochure

Things to Remember:

- All participants must be able to hike 1-3 miles and be on their feet for several hours at a time.
- Bring PLENTY of water. A good rule of thumb is 1 quart per person, per hour.
- Bring a lunch or snacks.
- We will be working off trail and long sleeves and pants will help protect you from spiny and thorny vegetation, as well as the sun.
- Wear sturdy shoes: Hiking boots or sturdy tennis shoes will do. Good shoes protect you from cactus spines.
- RSVPs are required so we bring enough equipment for everyone to participate.

NATIONAL PARK SERVICE

friends of SAGUARO NATIONAL PARK

Contact us:

For reservations and more information visit our website:
http://sites.google.com/site/sagusection17
or contact Irene Weber or Don Swann.
Email: Irene_Weber@partner.nps.gov
Phone: (520) 733-5177

2011 SECTION 17 SAGUARO CENSUS

A Volunteer Opportunity at SAGUARO NATIONAL PARK

What is the Section 17 Saguaro Census?

Shortly after the Saguaro National Park was established in 1933, park rangers noticed a decline in saguaros in the Cactus Forest area on the east side of Tucson. In order to study why the cacti were dying, all saguaros were measured and counted in a one square mile section of the park called Section 17. Smaller plots within the section have been studied ever since.

In the winter of 2011-2012, Saguaro National Park is re-surveying Section 17 in its entirety for the first time in 70 years. The information we are gathering will help park scientist better understand the life cycle of saguaros, factors that effect their health, and how the ecosystem has changed over time.

The Cactus Forest area of Saguaro National Park East has changed significantly over the last century

What do we know so far?

Saguaro populations declined in Section 17 from the late 1930s until the 1970s. There are still fewer saguaros than there were in 1941, but there are significantly more small saguaros, which means the future of this section is bright. For more details visit our website and look at the "Results So Far" page.

What will I be doing as a census volunteer?

Volunteering with the National Parks is a great way to give back to the environment and see parts of the park that most people don't get to see. As a volunteer with the Saguaro Census, you'll be acting as a "Citizen Scientist," helping park staff collect valuable data which will be used to better understand and better protect the saguaro cactus.

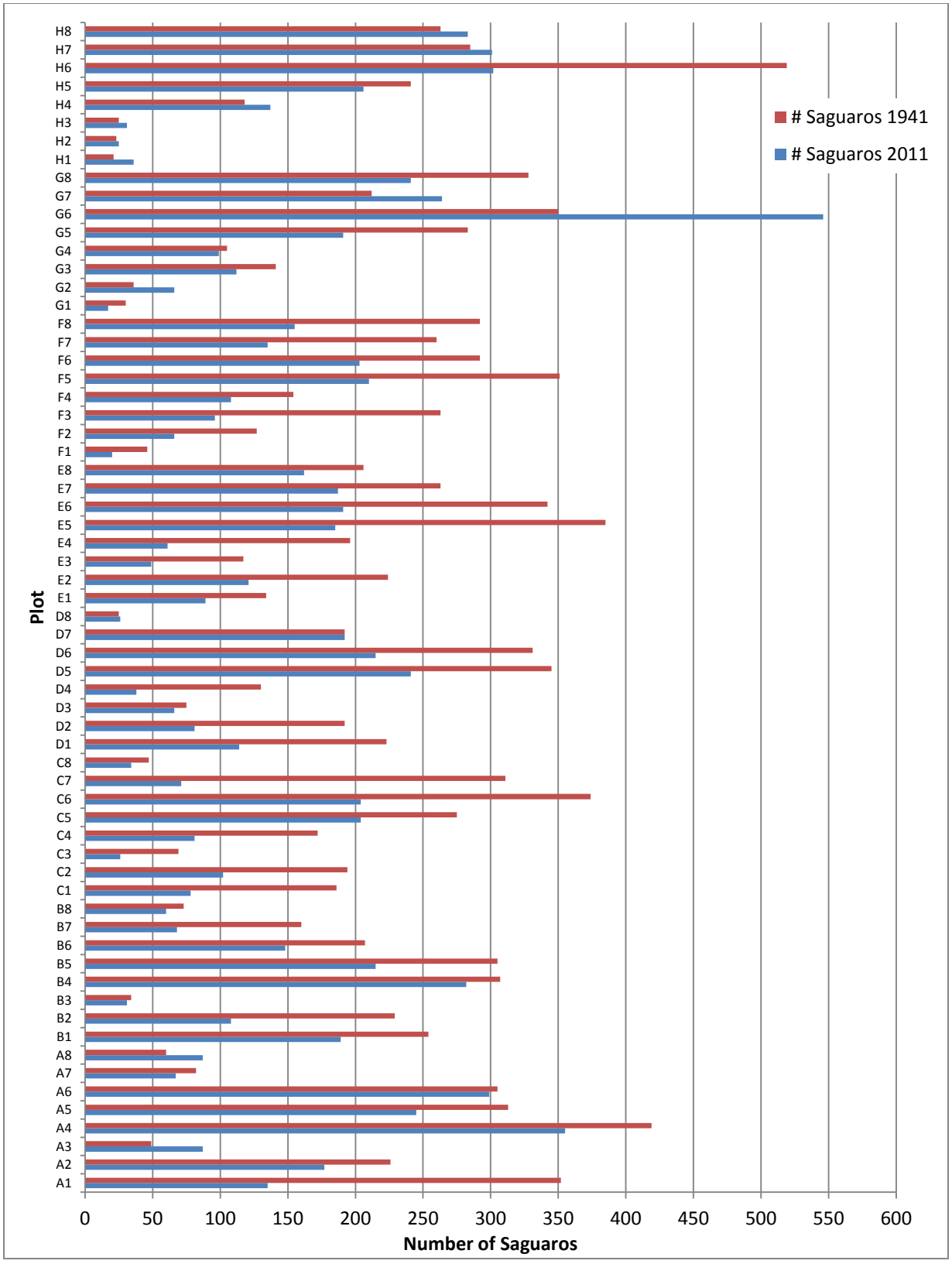
Section 17 is split up into 200 meter by 200 meter plots. All the saguaros within each plot are counted and measured. The small saguaros are measured using meter sticks and the large ones with clinometers, a tool that estimates heights using percent slopes and basic math. All participants work in teams and are trained in the field.

Who can participate?

Just about anyone! If you have a club/group/class interested in working on this project please let us know! We highly encourage groups of 10-20 sign up but we can use individual volunteers as well.

The terrain of Section 17 is pretty mild, so if you're used to light-moderate hiking, you'll do fine in this area. We will be working off trail, so wear sturdy clothes that will protect you in the brush, and sturdy shoes for uneven terrain.

Appendix D – Plot-level histogram of saguaro cacti in 1941 and 2012



Appendix E - Using repeat photography to predict the visual characteristics of the Cactus Forest in 2050

Introduction

Saguaro National Park East (SNPE) was established in 1933 to protect the giant saguaro (*Carnegiea gigantea*) that dominated the landscape. Repeat terrestrial photography of the saguaro cactus forest exists dating back to 1935 and shows a landscape nearly devoid of shrubs but with a uniform demographic of the giant saguaros. The decline in the numbers of larger, mature saguaro cacti that dominated the forest was documented in the 1940s (McAuliffe 1996). Subsequent repeated images from 1998 and 2010 visually documented the dramatic change to the cactus forest with respect to age and structure demographics (Fig. 1). Scientific studies determined that woodcutting and livestock grazing prior to the establishment of SNPE prevented recruitment of subsequent generations of giant saguaro cacti (Abouhaidar 1992, Niering et al. 1963, Steenbergh and Lowe 1983, Turner 1992.)

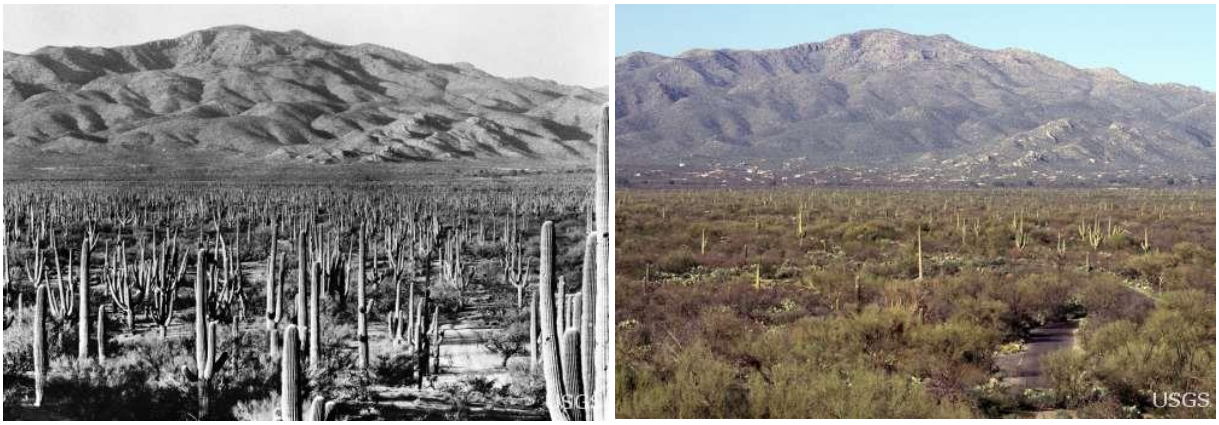


Figure 1 – The cactus forest in 1935 is shown on the right, while the 2010 image is on the left.

The giant saguaro species is long-lived. Juvenile cacti may take 40 to 100 years to reach a height of four meters, depending on the local factors that influence growth (Steenbergh and Lowe 1983). Without woodcutting to prune back shrubs, mesquite, creosote, and brittlebrush increased in abundance. These shrubs act as nurse trees for the giant saguaro but block visitor's views of regeneration that may be taking place within the cactus forest area.

The goal of this project is to produce an image predicting the view of the cactus forest in 2050 (Fig. 2). Our objectives are to survey the immediate foreground of the recent terrestrial photographs for juvenile saguaros, use age-size growth curves to predict the further growth of established saguaros, and remove mature saguaros from the photograph that reach the end of their life cycle.

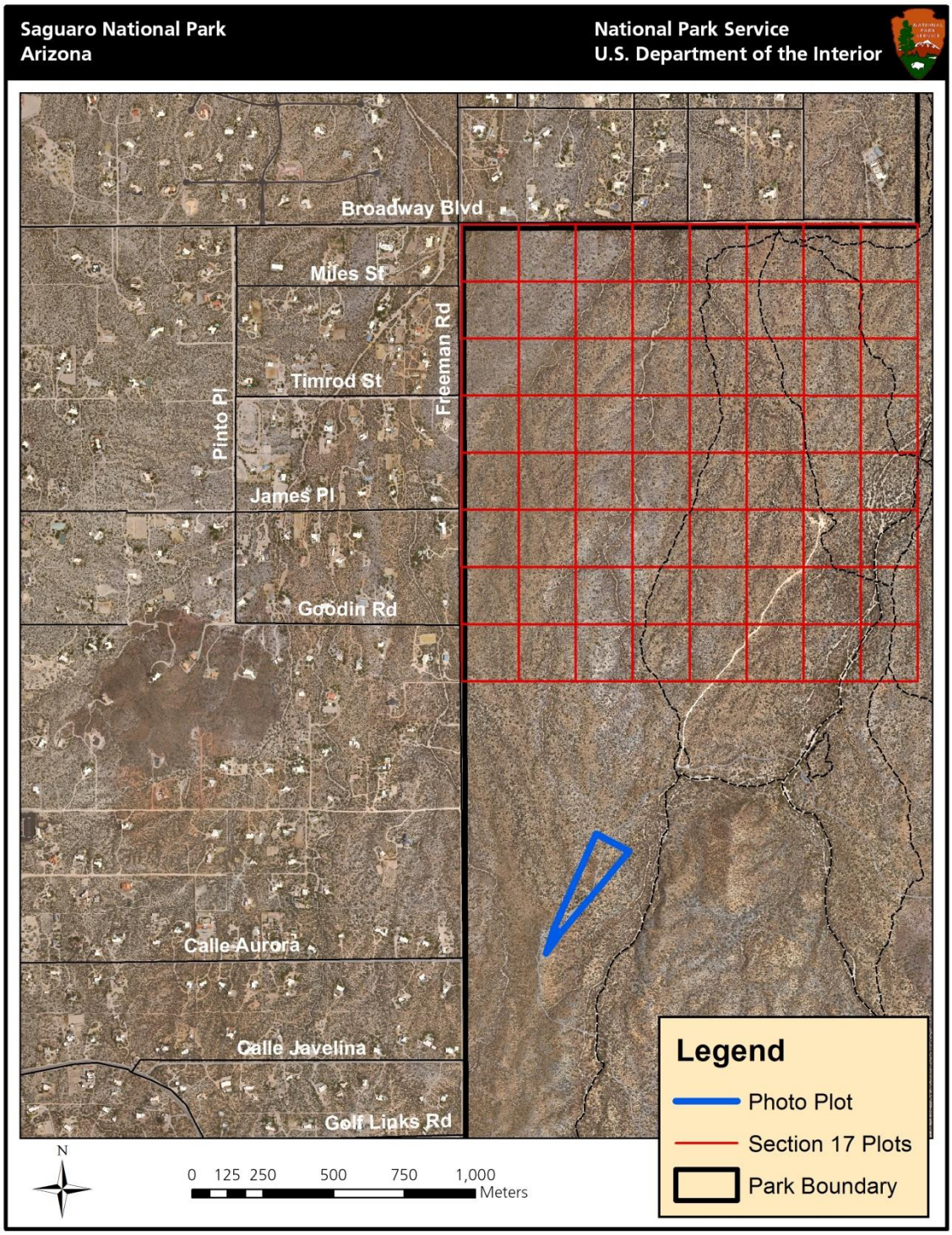


Figure 2 – Location of the repeat photography plot. The study area is just south of Section 17. The coordinates of the origin, where the photographer stands, are 524981 E, 3562378 N (UTM Zone 12N, NAD 83).

Methods

Determine area of inference: The foreground of the repeat images has the best potential for showing ecological change within the cactus forest. Determining the extent of the foreground is critical to the success of this project. We did not modify the 2010 image background in the final 2050 predicted image. We determined the spatial extent of the foreground by placing one crew member (observer) on the camera spot and observing a second crew member walk through the area with a GPS unit and a stadia rod. The observer recorded where the second crew member is visible and where the stadia rod could be seen through the shrubs on the 2010 image. When the second crew member disappeared or could not be distinguished from the surrounding environment, the UTM coordinates were recorded and we calculated the distance from the camera location using ArcMap. Using this method, we surveyed all areas 350 meters and closer to the camera location.

Survey the area: Using a handheld GPS unit, a field crew surveyed the area of inference for all saguaros following the protocol in Appendix B (Swann et al. 2011). The positions and heights were recorded for projection into the 2050 image.

Assumptions: This project relies on several assumptions. First, we do not account for changes in climate affecting saguaro growth curves or saguaro mortality. Second, shrub vegetation does not increase or decrease in density or change structure or composition. Third, we did not visualize any saguaros that may germinate between 2012 and 2050. The result is based solely on saguaros found in the field. Fourth, cacti that exceeded 160 years of age in 2050 according to the age-growth curve were removed and assumed dead.

Composing the image: We used Photoshop to make the corrections to height and density for the 2050 image. The 2010 image served as the background. By measuring the heights of existing cacti in the photo area of the 2010 image, we calibrated the heights of all cacti in the image. We determined the height of each saguaro cactus in 2050 by applying the growth curve from Steenbergh and Lowe (1983). Cacti obscured by vegetation are placed relative to known cacti or visible physical features such as the road, parking turn-offs, and landscape features. Satellite images also assisted with this procedure, resulting in a pseudo-triangulation of saguaro location. 64% of the surveyed saguaro cacti could be placed in the image using this method. The remaining 36% were either obscured by vegetation or could not be visualized with any confidence regarding location. Size, number, and direction of arms were placed randomly, but all saguaros with arms are old enough to grow arms.

Results

Our survey found 116 saguaro cacti. 55.2% of the surveyed saguaro cacti fall within the smallest height class (Fig. 3), indicating that the saguaro population is dominated by juveniles. Three saguaros were taller than 8.2 meters, and all three were assumed to be dead in 2050. Saguaro height ranged from 15 centimeters to 1010 centimeters (Fig. 3). This range increased to 391 cm to 1263 cm in 2050 according to the growth curve calculations (Fig. 4). The final product is shown in Figure 5.

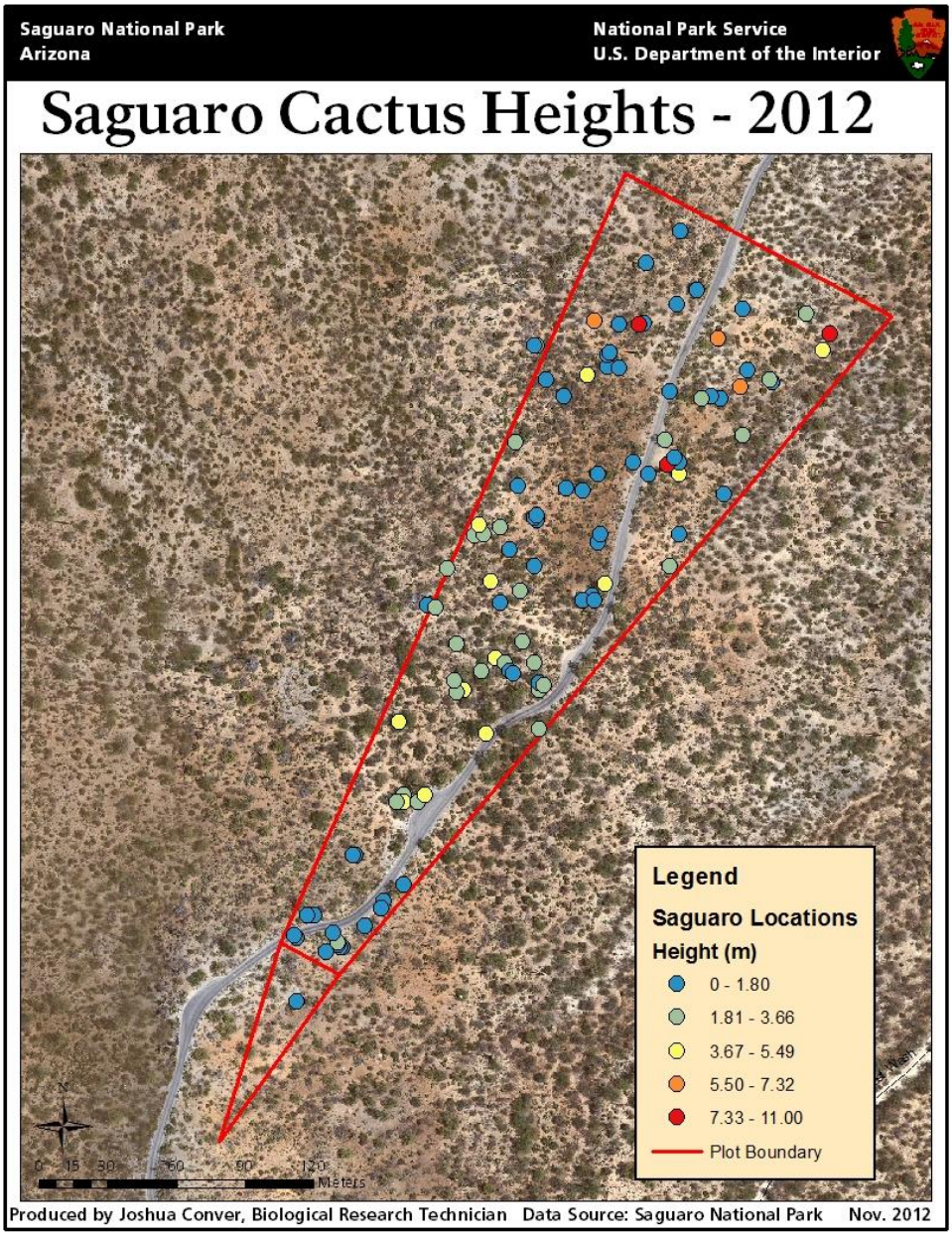


Figure 3 – Location and heights of measured saguaros in 2012.

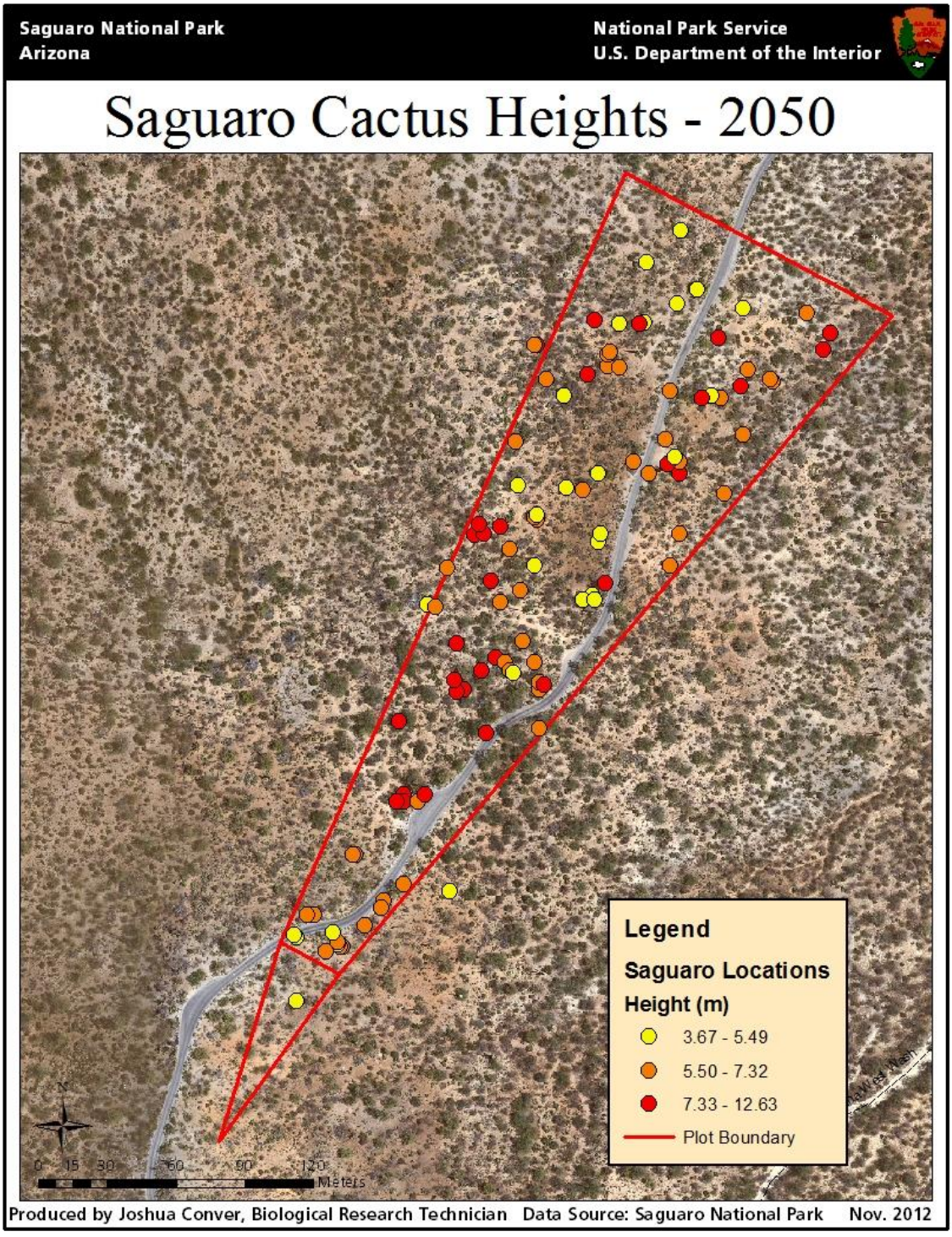


Figure 4 – Calculated 2050 saguaro heights for cacti located and measured in 2012. This map is the basis for the image produced with Photoshop.

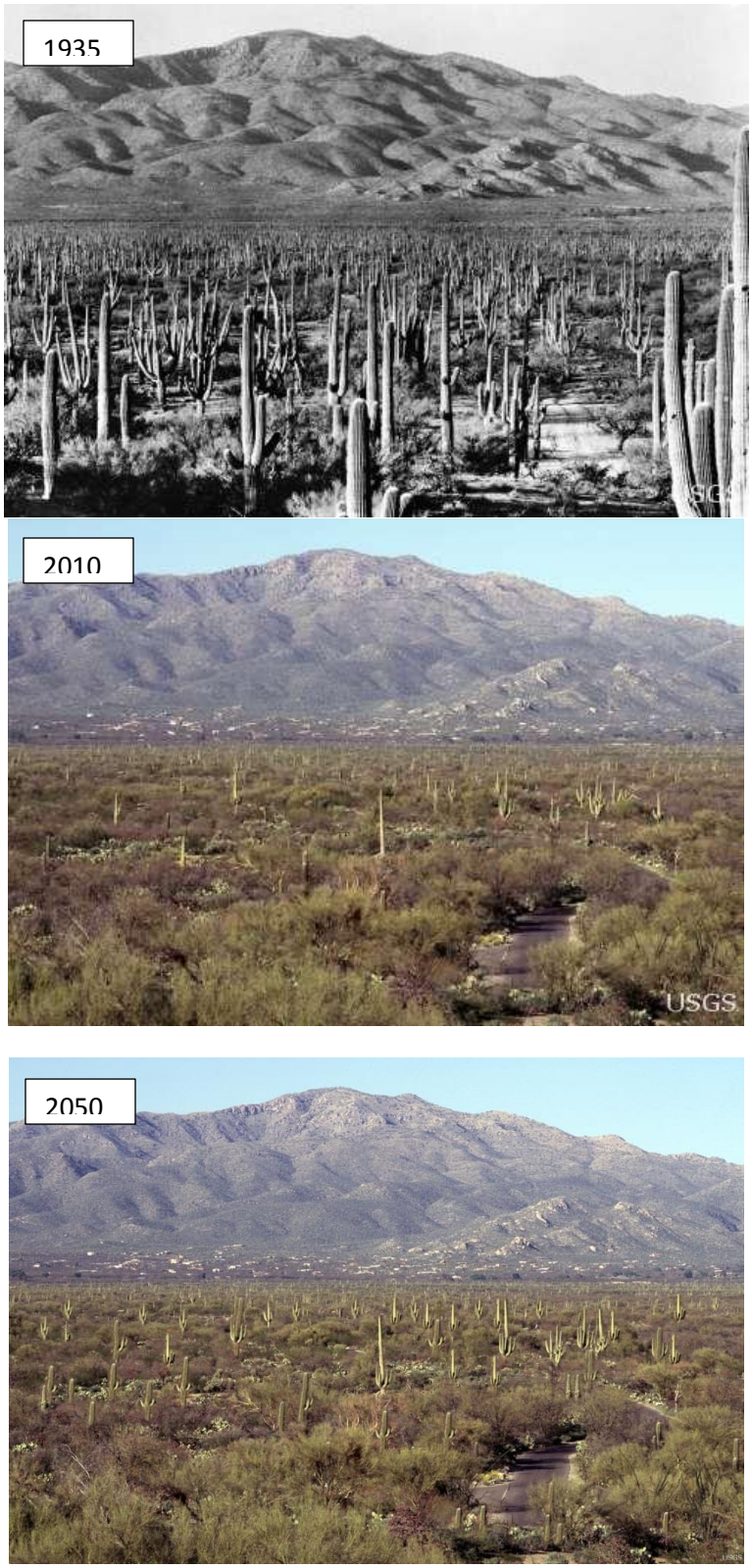


Figure 5 – Chronological view of the cactus forest. We determined that 36% of the cacti currently located within the near frame of the 2050 photo would be obscured by vegetation in 2050, and are not shown.

Discussion

The 2050 image shows a significant number of saguaro cacti will be visible above the shrubs in the foreground compared to the 2010 image. The number of saguaro cacti will not return to the 1935 level for some time, but the predicted 2050 image provides some indication of what visitors can expect to see. The aesthetic quality of the Cactus Loop Drive is predicted to increase, ensuring that future visitors to Saguaro National Park will enjoy the view of the cactus forest. Technicians from Saguaro National Park should be encouraged to continue the repeat photography on a regular basis to document the change in land cover and viewshed. Repeating the photography project will also serve as a validation of the method presented. This method is not recommended for locations that are subject to changes in physical terrain, such as steep slopes, areas susceptible to erosion or other mass movement phenomenon, or drastic changes in land use. The stability of this landscape and National Park Service protection add significant confidence to the result.

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